INTERNATIONAL COLLABORATION ON ADVANCED NEUTRON SOURCES

ICANS-III

Conference on Target Stations and Accelerator Technology

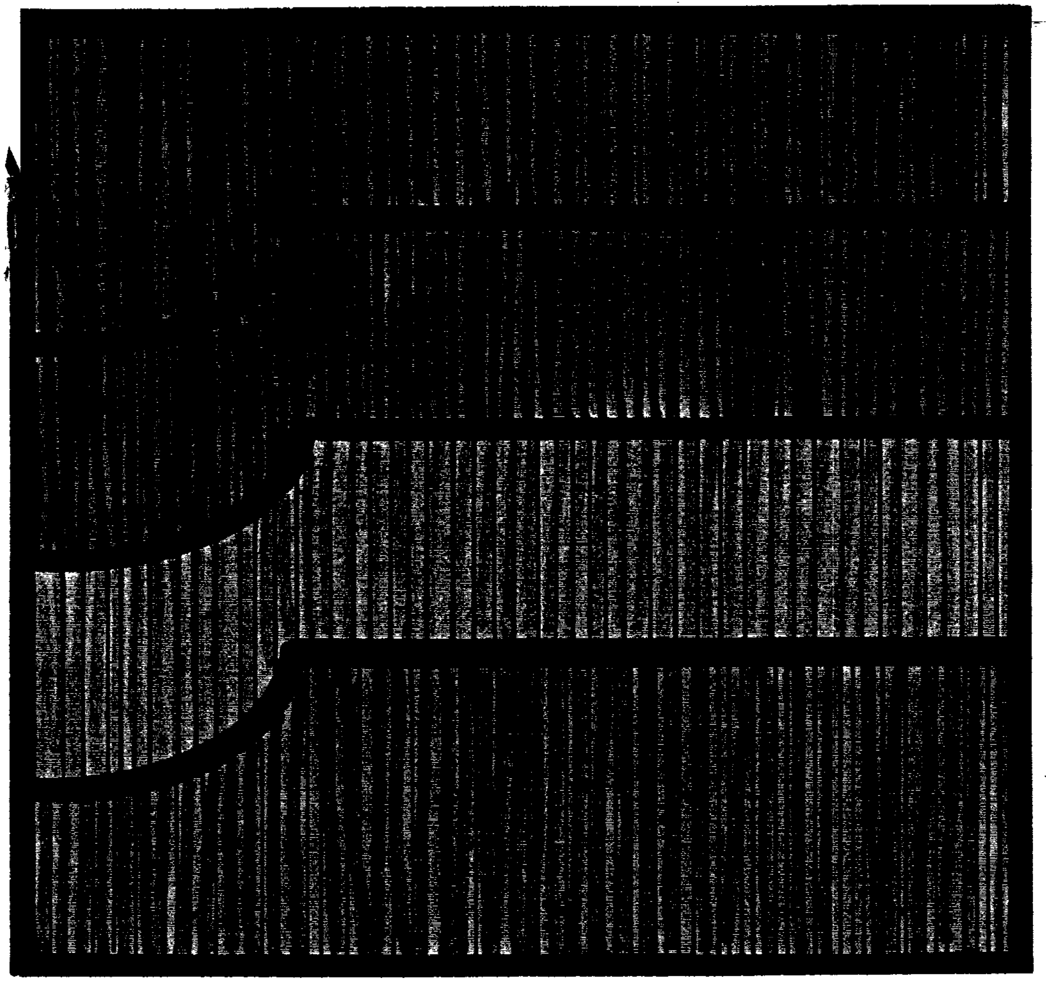
Los Alamos Scientific Laboratory

March 19-22, 1979

Compiled by

Gary J. Russell

International Collaboration on Advanced Neutron Sources



ICANS III

March 19 - 22, 1979
National Security and
Resources Study Center
Los Alamos, N.M.

POSSIBLE TOPICS FOR ICANS-III

Accelerator Technology

Extraction, Fast Kickers

Intense H^- Sources

Injection

Magnet Power Supplies

Magnet Design and Fabrication Techniques

Vacuum System

Strippers

Beam Instabilities and Control

Beam Losses, Beam Scraping, and Activation Problems

Beam Induced Multipactoring

RF Systems

Remote Handling Considerations

Beam Diagnostics

Particle-Tracking/Simulation-Codes

Instrumentation and Control Systems

Vacuum Vessel RF Shield

Beam Losses in Linac

Application requirements

Target Station

Target/Moderator/Reflector Design

Experimental-Data/Code-Verification

Cold Moderator Design

Neutronic Decouplers

Beam Port and Plug Design

Safety Studies

Target Station Diagnostic and Services

Target Station Shield Design

Target Station Operational Aspects (e.g. Scheduling, Shut-Down Procedures)

Target Instrument.

Failure Mech.

Windows

Target test results & proposals

AGENDA

Monday, March 19, 1979

0815	Bus Pickup - Lobby of Los Alamos Inn to Study Center
0830-0900	Registration - Study Center
0900-0915	Opening Remarks - G. J. Russell, LASL
0915-0930	Welcoming Address -- ~~G. A. Keyworth~~, LASL J. C. Solem
0930-1000	Summary of Intense Pulsed Neutron System (IPNS) - N. J. Swanson, ANL Trevor
1000-1030	Summary of Spallation Neutron Source (SNS) - J. T. Hyman, RL
1030-1110	Coffee Break John
1110-1140	Canadian Accelerator Projects - J. S. Fraser, CRNL
1140-1210	TRIUMF Thermal Neutron Facility - I. M. Thorson, TRIUMF
1210-1315	Lunch - South Mesa Cafeteria Len
1315-1345	SIN Thermal Neutron Facility - W. E. Fischer, SIN
1345-1415	West German Spallation Neutron Source Project - J. E. Vetter, Karlsruhe
1415-1500	Group Picture and Coffee Break
1500-1615	Divide Into Two Groups (Accelerator and Target Stations) and Formulate a Preliminary Agenda for Remainder of Week
1615-1715	Convene Both Groups and Formulate a Final Combined Agenda for Remainder of Week
1715-1830	Director-Hosted Reception in Study Center
1830	Bus Pickup - Study Center to Los Alamos Inn

Conference Telephone Number (505) 667-5752

AGENDA

Tuesday, March 20, 1979

0800	Bus Pickup - Lobby of Los Alamos Inn to LAMPF Auditorium
0815-0845	Status of LAMPF - D. C. Hagerman, LASL
0845-0915	Summary of Weapons Neutron Research Facility (WNR) - G. J. Russell, LASL
0915-0945	Summary of Proton Storage Ring (PSR) Project - G. P. Lawrence, LASL
0945-1015	Coffee Break
1015-1210	Separate Working Group Sessions (Accelerator and Target Station
1210-1315	Lunch - South Mesa Cafeteria
1315-1500	Separate Working Group Sessions (Accelerator and Target Station
1500-1530	Coffee Break
1530-1700	Separate Working Group Sessions (Accelerator and Target Station
1700-1720	Combined Working Group, Summary Session
1720	Bus Pickup - LAMPF Auditorium to Los Alamos Inn

1015 -1210

Conference Telephone Number (505) 667-5429

AGENDA

Wednesday, March 21, 1979

0800	Bus Pickup - Lobby of Los Alamos Inn to LAMPF Auditorium
0815-0925	Combined Working Groups
0925-0945	Film on LAMPF
0945-1015	Coffee Break
1015-1210	Tour LAMPF and WNR
1210	Transportation from LAMPF to Los Alamos Inn
1330-1630	Transportation Provided for Skiing, Touring, Special Work Sessions, Visits, etc.
1800-1900	Transportation Provided from Los Alamos Inn to (No-Host) Dinner in Santa Fe
2100-2200	Transportation Provided from Santa Fe to Los Alamos Inn

Conference Telephone Number (505) 667-5429

AGENDA

Thursday, March 22, 1979

0800	Bus Pickup - Los Alamos Inn to Study Center
0815-0845	Combined Working Group, Summary Session
0845-1015	Separate Working Group Session (Accelerator and Target Stations)
1015-1045	Coffee Break
1045-1210	Separate Working Group Session (Accelerator and Target Stations)
1210-1315	Lunch - South Mesa Cafeteria
1315-1345	Combined Working Group, Future Planning Session
1345-1500	Writing of Summaries
1500-1530	Coffee Break
1530-1645	Writing of Summaries
1645-1715	Combined Working Group, Summary Session
1715	Bus Pickup - Study Center to Los Alamos Inn

Conference Telephone Number (505) 667-5752

-NOTES-

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- NOTES -

FOREWORD

The third meeting of the laboratories involved in the International Collaboration on Advanced Neutron Sources (ICANS) was held at the Los Alamos Scientific Laboratory from March 19-22, 1979. Seventy-six people from seven countries participated in ICANS-III. The two general topics covered during the conference were target stations and accelerator technology.

The original membership of the ICANS consisted of: a) Los Alamos Scientific Laboratory (U.S.), b) Argonne National Laboratory (U.S.), c) Rutherford Laboratory (U.K.), and d) KEK Tsukuba (Japan). Steps are being taken to expand the membership of the ICANS, subject to the agreement of laboratory management, to include: a) Swiss Institute for Nuclear Research, SIN (Switzerland), b) KFA Laboratory Jülich (West Germany), c) KFK Laboratory Karlsruhe (West Germany), d) Chalk River Nuclear Laboratory (Canada), and e) TRIUMF (Canada).

At ICANS-III, the objectives of the ICANS were restated as follows:

- to provide a means for informing participants about plans relating to the development and exploitation of pulsed and steady-state spallation neutron sources
- to facilitate the exchange of technical information
- to provide a forum for review of results and designs
- to reduce duplication of effort
- to identify areas for collaborative endeavors.

I especially want to acknowledge the help of M. F. Gomez in typing and organizing the ICANS-III summary. I appreciate the help of all the ICANS-III participants who contributed to the success of the conference and who directly contributed to this conference summary. In particular, I acknowledge the assistance of John L. Yarnell who helped proofread the plenary and target station sections, and Richard K. Cooper who helped compile and proofread the section on accelerator technology. We made no attempt to extensively edit your contributions. Since this summary does not constitute a formal publication, anyone wanting to quote information from it outside the context of the ICANS should obtain permission from the original author.

Gary J. Russell
Physics Division
Los Alamos Scientific Laboratory
September 1979

CONTENTS

III. GENERAL SESSIONS - ACCELERATOR TECHNOLOGY

INTERNATIONAL COLLABORATION ON
ADVANCED NEUTRON SOURCES

ICANS-III

Conference on Target Stations and
Accelerator Technology

Los Alamos Scientific Laboratory

March 19-22, 1979

Compiled by

Gary J. Russell

ABSTRACT

The third meeting of the International Collaboration on Advanced Neutron Sources (ICANS) was held at the Los Alamos Scientific Laboratory from March 19-22, 1979. The general topics discussed were target stations and accelerator technology. Seventy-six people from seven countries attended the conference. The conference summary contains brief descriptions of specific topics covered during the four-day meeting.

I. PLENARY SESSIONS

Plenary sessions were held during the first day and part of the second morning of ICANS-III. Twelve formal presentations were made during these sessions. The intent of the plenary sessions was to have a representative from each of the laboratories which are formally members of the ICANS (and those laboratories interested in joining the ICANS) summarize the status of the various spallation neutron source projects and related activities. In this way, everyone at ICANS-III could simultaneously be informed, and the knowledge gained would aid in making the remaining sessions of ICANS-III more productive.

Johndale Solem, Alternate Physics Division Leader at LASL, officially welcomed the ICANS-III participants, briefly described LASL, and discussed the role of the Weapons Neutron Research Facility (WNR) as a pulsed-neutron source.

A. Status of the IPNS Program, N. J. Swanson, ANL

1. Overall Summary

During the past year the Intense Pulsed Neutron Source (IPNS) program has been involved in two principal activities. These have been to prepare for the design of the IPNS-I construction work and to operate the ZING-P' prototype facilities. To accomplish both of these main tasks it was necessary to develop an organizational structure and establish policies and procedures under which this organization is to function. The organization encouraged four distinct groups: a) accelerator-systems operations and Research and Development (R & D), b) source and instrument operations, c) applications R & D, and d) IPNS-I project design and construction.

During this period the accelerator completed its first year of operations. Many problems were encountered, some of which were solved and corrected. Some prototype instruments came into operation and these are now producing meaningful data. The IPNS-I construction project was authorized by the Congress and the work on preliminary engineering was begun based on concept design work completed during the past year. IPNS-I is expected to become operational in mid-1981.

2. ZING-P'

a. ZING-P' Operations - 1978

Operation of the ZING-P' began in December 1977. By April 1978, protons were delivered from the Rapid Cycling Synchrotron (RCS) to a tungsten target at a rate of $\sim 6 \times 10^{11}$ protons/pulse at repetition rates of about 10 Hz (effective rate of about 7 Hz due to time sharing of the linear accelerator with ZGS). In July 1978, a period of dedicated operation at repetition rates of 15 Hz was provided. In late 1978, with shared operation of the linac, the prototype was operated at 15 Hz (effective rate of about 10 Hz) delivering an average of 8×10^{11} protons/pulse. The ZING-P' target/moderator system delivered neutrons through one of the three horizontal-beam tubes to a High-Resolution Powder Diffractometer where meaningful high-quality data was produced. Outfitting of the two remaining horizontal-beam tubes was begun with a Single Crystal Diffractometer and Chopper Spectrometer. A Crystal Analyzer Spectrometer and High-Intensity Diffractometer were installed in the two vertical neutron-beam tubes. The latter was replaced with an Ultracold Neutron Generator towards the end of the year.

Initital operations of the RCS (formerly known as Booster II) revealed excessive proton losses particularly in the extraction system. The high losses led to high-radiation background levels, caused by activation of accelerator components, which severely limited personnel access to those areas where routine access was needed. Therefore, the accelerator was shutdown for two months while additional shielding was installed. This shielding reduced the radiation levels in the areas desired for routine, uncontrolled occupancy by a factor of four. The addition of more shielding is impractical for space and structural reasons. A major attempt is being made to understand and correct the proton loss problem.

b. ZING-P' Operations - 1979

At the beginning of the year the extraction-septum magnet failed. Radiation levels from proton activation were found to be quite high. After a decay period of about one month, the magnet was removed and replaced with a new unit. The overall shutdown period was seven weeks. Advantage of the shutdown was taken to prepare for some special experiments. These included the following:

- Target measurements and neutron-beam intensities for the existing tungsten were found to be needed to substantiate calculated estimates. These activities were performed in early March as soon as the accelerator operations were resumed.

- Neutron-flux spectrum and damage-function measurements were made with a tantalum target in a mockup of the IPNS-I Radiation Effects Facility. These are considered necessary as base information to establish the type of target material (tantalum or uranium) to be used in the IPNS-I Radiation Effects Facility target. The measurements were completed in mid-March.

- Neutron-flux spectrum and damage-function measurements are to be made with a uranium target for the same reasons as described above. These measurements will be performed in early April.

- Target-power, temperature-distribution, and beam-intensity measurements on the uranium target will be performed in April or May.

When the above measurements are complete, routine (neutron-production) operations will be resumed using a newly fabricated uranium target which has been clad with Zircaloy-2. These operations will be at a repetition rate of 15 Hz (effective rate of 10 Hz) through September 1979.

In October and November changes will be made in the accelerator to improve its performance, particularly the extraction efficiency and reliability of the extraction septum magnet. The latter includes the replacement of the septum assembly with a newly designed transformer coupled unit. At the end of September the ZGS will be shutdown and phased out. This will permit dedicated operations of the H^- source and linac for the ZING-P' system. When this occurs the repetition rate will be increased to 30 Hz which will also become the effective rate since time sharing with ZGS will no longer be needed. At the higher repetition rate the expected neutron-production rate in ZING-P' (at a delivered charge of $\sim 8 \times 10^{11}$ protons/pulse) will be $\sim 2 \times 10^{14}$ neutrons/s.

c. ZING-P' Operations - 1980

Six months of operation are scheduled for 1980. The operating conditions are expected to be the same as in late 1979, with efforts continued to improve operating efficiency. Late in the year the ZING-P' system will be shutdown and phased out. At that time the construction needed to route the RCS proton output to the IPNS-I facilities will be undertaken.

3. IPNS-I Construction

a. System Description

The IPNS-I will use the same H^- source, linear accelerator, and 500-MeV synchrotron which was used for ZING-P'. The design and construction will include the following:

- a 500-MeV proton-beam transport line from the RCS to the IPNS-I targets
- a beam dump to permit tuneup and other accelerator diagnostic work while the IPNS-I targets are being serviced, modified, or otherwise out of service
- a target/moderator/reflector system to produce thermalized neutrons for neutron-scattering experimentation
- a target/reflector system to produce fast neutrons for radiation-damage work
- about five neutron-scattering instruments together with their data acquisition and processing systems
- biological shielding and miscellaneous services for all of the above.

The IPNS-I facilities, for the most part, will be housed in existing buildings and use existing facilities vacated by phase out of the ZGS. The layout of the biological shield for IPNS-I is shown in Fig. I-A.1.

b. Design and Construction Schedule

Funds for the IPNS-I Project have been received and the design work has been started. Construction will begin in mid-1979, and be completed in mid-1981, at which time initial operations of IPNS-I are expected to begin.

c. Cost-Estimate Summary

The cost estimate for the IPNS-I facilities outlined above is $6.4 M. These funds were authorized for FY-1979. In the President's budget for FY-1980 is an additional $3.0 M for an IPNS-I upgrade. These funds will be used for provision of additional neutron-scattering instruments and for cryogenic systems for the Radiation Effects Facility irradiation thimbles.

d. IPNS-I Instruments

The initial complement of neutron-scattering instruments has been selected. Work to develop the design requirements for these instruments will be initiated in April 1979.

e. Target Systems

Preliminary engineering of the target systems was initiated in March 1979. At present it is expected (contingent upon evaluation of the Radiation Effects Facility mockup measurements) that identical water-cooled uranium targets will be used for both neutron-scattering and radiation-effects systems. A summary of the target activities are the following.

Work Completed

- general analytical study
- target-reference design
- thermal- and elastic-stress analyses
- basic heat-removal analysis
- target-cooling system reference design
- concepts for irradiated targets and moderator/reflector handling
- analysis of ZING-P' uranium target

Work in Progress

- prototype work on cladding techniques
- design and fabrication of uranium target for ZING-P'
- refinement of biological shield design
- reference design for neutron-scattering moderator/reflector assembly
- reference design for radiation-effects reflector assembly.

f. Long-Range Plans

The IPNS-I is to be a user-oriented national facility. The policies for its operation and use have been defined. Operating programs are now being developed. Design features are being incorporated to assure maximum versatility to accommodate different target/moderator combinations and a full variety of research instruments. In addition, capabilities are included to permit expansion of the operational scope to include such facilities as neutron radiography, proton irradiation, and neutron activation. Considerable effort is being applied to provide features which will assure good operating efficiencies so that users' requirements can be satisfied in a timely manner.

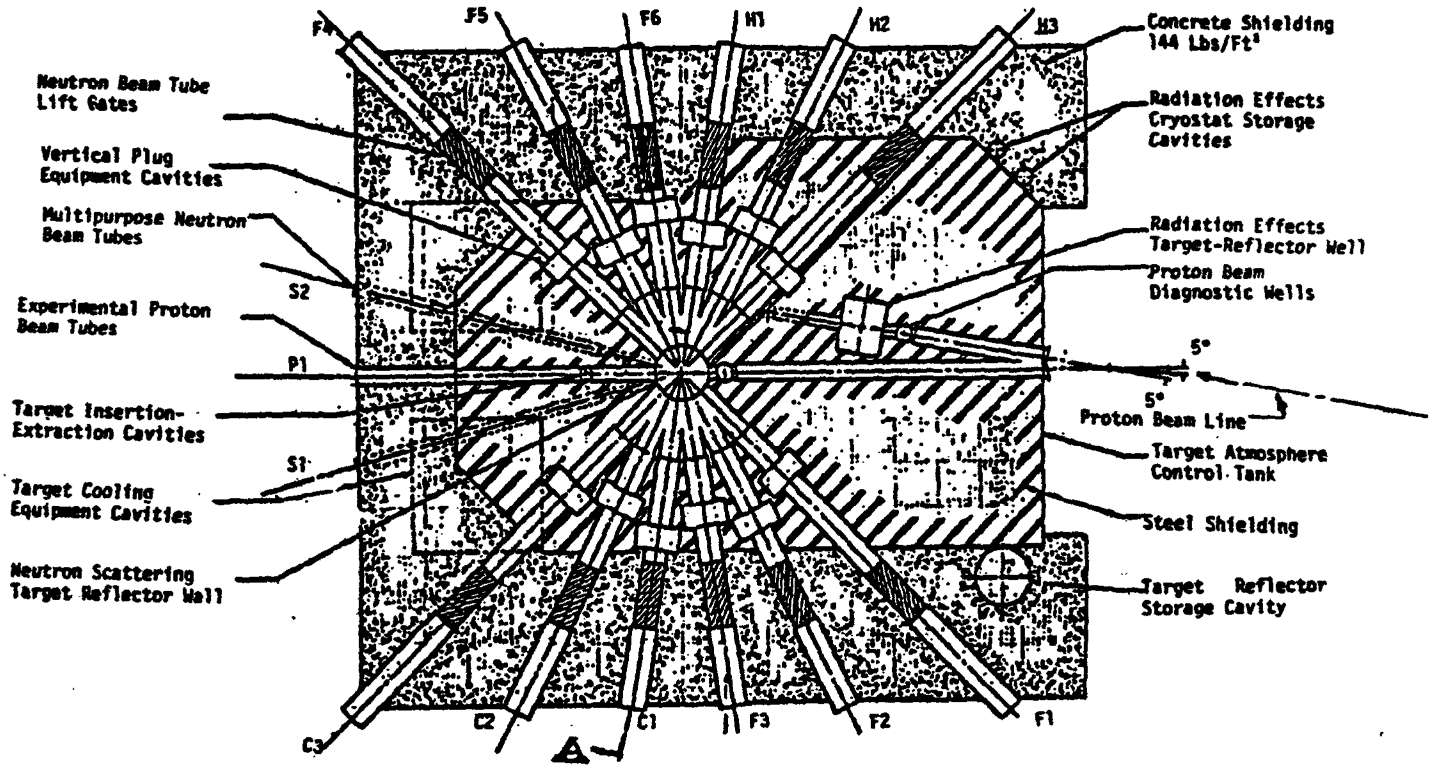

Fig. I-A.1. IPNS-I biological shield layout.

B. The SNS Project, J. T. Hyman, RL

1. General

My intention is to give an overview of the present Spallation Neutron Source (SNS) project in a very general way. Many of the team leaders responsible for the various parts of the machine and experimental facilities are here in person, and it would be most presumptuous of me to go into detail.

You will no doubt remember that just prior to the ICANS-II meeting at Rutherford (July 11-14, 1978), the NIMROD facility had been closed down. Since then, considerable efforts have been under way to strip down the old machine, and to dispose of unwanted material and equipment. This is being offered to universities, schools, or sold as scrap. A firm specializing in reclamation is dismantling the old rotating power supply and associated transformer/rectifier equipment and is still going to pay us a worthwhile sum!

Although no new buildings are necessary for the SNS, there are a considerable number of significant alterations and additions to be done. Among these alterations is the new control center due for completion in July. The layout of the SNS Facility is illustrated in Fig. I-B.1.

2. 70-MeV Linac

Modifications to upgrade the 70-MeV Linac from the original 1 Hz to the required 50 Hz operation for the SNS are progressing. A prototype modulator has been run and rf fed into tank 4. The rf valves are able to deliver the required power, but more work has to be done on increasing the ratings of rf parasitic suppression and to overcome heating problems in the driver anode blocking capacitors. The rf stages are identical for all four tanks.

An H^- ion source assembly has been designed and most parts are being manufactured. Tests are expected to start in July. The source is of the cesium-activated Penning type and is expected to be happiest running at a fixed-duty cycle. A HEDS chopper, which is a modified old 15 MeV HEDS chopper, is being proposed for short-pulse injection studies. Additional shielding for the Linac has been specified. The basic design of the 70-MeV transport line has been done, and work is being carried out on improvements to the beam diagnostics.

3. Synchrotron Ring

Minor changes have been made to the magnet lattice and the location of most of the correction elements has been specified (orbit-correction dipoles, trim quadrupoles, skew quadrupoles, octupoles, etc.)

Orders have been placed for 20 trim quadrupoles, 20 doublet quadrupoles (the first of these magnets are due for delivery about now). We are about to go out to tender for the 10 large bending magnets. The design of the remaining singlet quadrupoles is well advanced. A magnet-measurement system, based on one of the GEC 4070 control computers and using the GRACES control language interpreter/compiler, has been set up.

All of the capacitors for the main power supply have been received from Daresbury (from NINA). A new dc bias supply is to be purchased. An ac makeup supply has been decided upon, but whether the synchrotron will be locked to the mains (which vary in frequency as it does in the U.S.) or run at fixed frequency still is something of an open question. The problem area we have is the difficulty in maintaining accurate phasing of a number of rotating high-speed choppers in the neutron beam lines. The power supplies for the trim quadrupoles have been specified.

The ceramic vacuum vessel sections are on order and the design of the furnace for joining the sections is progressing. This work will be carried out in R4, which is the old converter building of the NIMROD PS. Much of the pumping equipment has already been delivered.

The high power rf system has been completely redesigned to take account of the characteristics of available ferrite. There will now be six two-gap cavities instead of the four three-gap ones as originally proposed. We are now in the process of evaluating tenders for the ferrite.

Development work is under way on a prototype cavity bias supply, and the system design for the control (phase and amplitude) for the six rf cavities has been completed. Hardware development of the low-power rf system is under way including a prototype primary frequency generator, machine-timing system, rf phase detectors, etc. Considerable thought is being given to the design of the rf shield and a number of measurements are planned on such things as flanges, bellows, etc.

A beam-position monitor for use in the ring and based on a ferrite or mu-metal cored induction coil has been designed and a prototype has been built and is being tested.

Control of beam losses in the ring is very important, and we are aiming to localize the losses to a few restricted regions. From injection up to 100-MeV the losses (as high as 50%) will be localized on a specially designed collector system. The predominant loss at higher energies will be on the septum of the extraction magnet.

The extraction system has been designed and from it the orientation of the synchrotron lattice decided. Experimental work is proceeding on magnetic measurements on an experimental ferrite kicker magnet driven from a test facility employing an artificial live and triggered spark gap. The final pulser will use high-voltage cables as the PFN and have a co-axial thyratron switch (design now well advanced).

4. External Proton Beam and Target Station

The External Proton Beam (EPB) has been designed and will use a total of 64 magnets (63 of these quadrupole and bending magnets, are available, from NIMROD, together with the necessary power supplies).

A preliminary design for a pion-therapy facility has been completed and is being costed prior to presentation to the Medical Research Council for funds (about now). An additional wide-aperture quadruple will be needed. The pion target will reduce the main target intensity by 10% and the facility will be mounted on top of the EPB shield.

The physics design of the target station is nearing completion, and some engineering proposals have been sketched for the arrangement of the shuttered holes. Eighteen holes at nominally 13° (giving 5 ft. between centers at the outside of the shield) are proposed.

Target plates are being developed by the Atomic Energy Research Establishment (AERE) Harwell under contract. Successful diffusion bonding and forming of target plates have been achieved (Zircalloy-2 clad, "Springfield" adjusted, uranium of different thickness plates) of sizes suitable for test on the Harwell linac.

Beryllium reflector blocks have been ordered as have 420 litres of D_2O (tritium < 1 Ci/ℓ). Work is continuing on the target cooling system. A detailed study of remote-handling problems associated with the target station has started. A model remote-handling cell is planned and remote master/slave manipulators ordered (the problems of need for remote handling elsewhere in the machine are being kept very much in mind).

5. Controls

The four GEC 4070 computers were delivered early in 1979 and are working well. The largest machine is in constant use for development of system software. Another is being used for the magnet-measurement system noted earlier. The other two machines are used to familiarize staff with GRACES and for development of equipment interfaces (CAMAC and a GP multiplex system). Prototypes of the data link CAMAC controllers are almost complete. The first software equipment/computer interface routines (data modules) are being written.

The importance of the control system should not (and isn't) being underestimated (perhaps my personal involvement in accelerator computer control systems makes me biased). However, the needs of the control system and a standardized approach are being written into all of the electrical equipment specifications.

6. Experimental Equipment

Although most of my comments have been related to the SNS itself, considerable work has been done on the experimental front (users). The first six instruments have reached the costing stage, scientific specifications have been agreed upon with the universities and financial approval will be sought in May. Design studies are continuing on other instruments, and it is planned to have 10-12 instruments available on day one (late 1982).

7. Overall

Sufficient information is now known about the availability of effort, money, and project requirements to make detailed overall planning a meaningful exercise. My personal view (and it is my personal view) is that 1982 is an achievable date if optimal use is made of the available manpower, no unnecessary work is done, and as much work as possible is "farmed out". Time alone will prove me right or wrong!

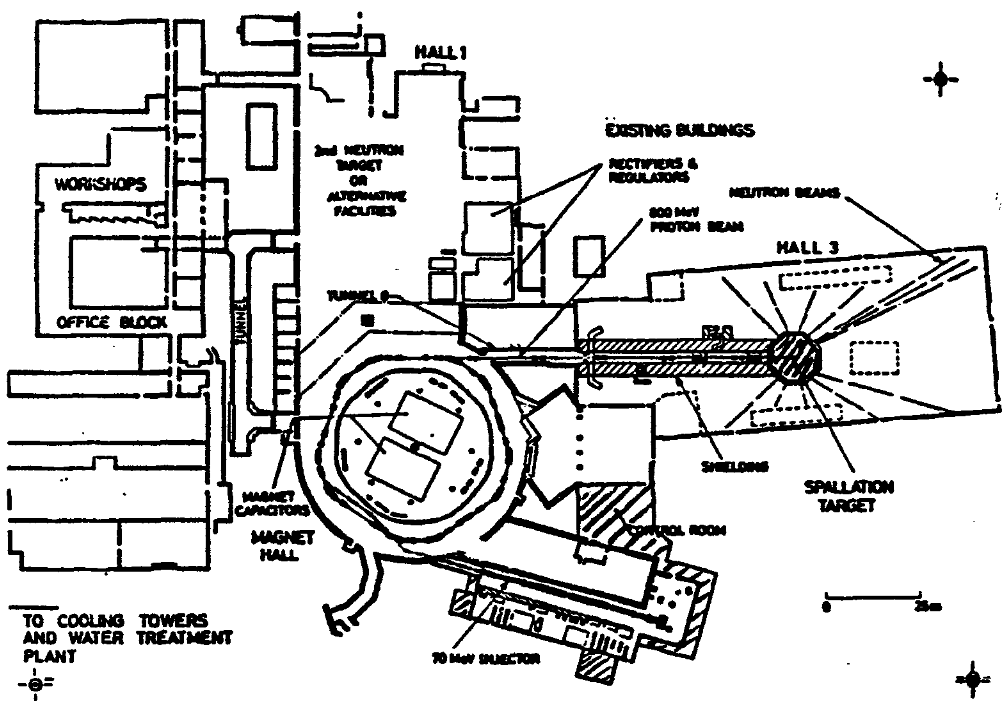

Fig. I-B.1. Layout of SNS facility. The magnet lattice is not up to date.

C. The KEK Neutron Source and Neutron Scattering Research Facility (KENS), H. Sasaki, KEK

The pulsed-neutron source facility (KENS) is under construction at the National Laboratory for High-Energy Physics (KEK), Tsukuba, Japan. The facility consists of a pulsed-neutron source produced by spallation in a massive target (either W or U) irradiated by a 500-MeV proton beam from the KEK booster synchrotron and of an experimental area for neutron-scattering research. The KENS project was planned as an extension to the neutron-scattering research program using a pulsed-neutron source (PNS) at the Laboratory of Nuclear Science, Tohoku University; the KENS project is considered as an intermediate step toward the final Japanese Pulsed Neutron Source Project.[1] In 1974, a technical workshop was organized under the auspices of a Grant in Aid for Scientific Researches (GASR) from the Ministry of Education, where the possibility of constructing a pulsed-neutron source by using a surplus proton beam from the 500-MeV booster synchrotron at KEK was discussed. The results were published in a technical report.[2] The proposal of the KENS project was then presented to the KEK Advisory Council for Scientific Policy and Management in May 1975, where the KENS was finally authorized as a KEK facility. The budget for construction of the facility was approved by the Government in February 1977. The facility is scheduled for completion in March 1980.

The KENS facility is now organized as one section of the KEK Booster Synchrotron Utilization Facility which has been in existence since April 1978. This latter facility includes, besides KENS, two other experimental facilities: a) the meson physics research facility, and b) the utilization of high-energy proton and neutron beams for medical and biological purposes. The layout of the KEK is displayed in Fig. I-C.1 and the details were reported separately.[3] Actual construction of the KENS facility is promoted by the construction workshop members organized under the auspices of the GASR.

An interim technical report describing the present status has been published.[4]

References

1. Technical report of the workshop (GASR) on "Repetitive Pulsed Neutron Source Project in Japan," March 1971.

2. Technical report of the workshop (GASR) on the KENS Project, March 1975.

3. H. Sasaki: A report presented at the 2nd ICANS Workshop, Rutherford Laborabory, July 10-15, 1978.

4. Technical report of the workshop (GASR) on "Construction of KENS Facility, July 1978.

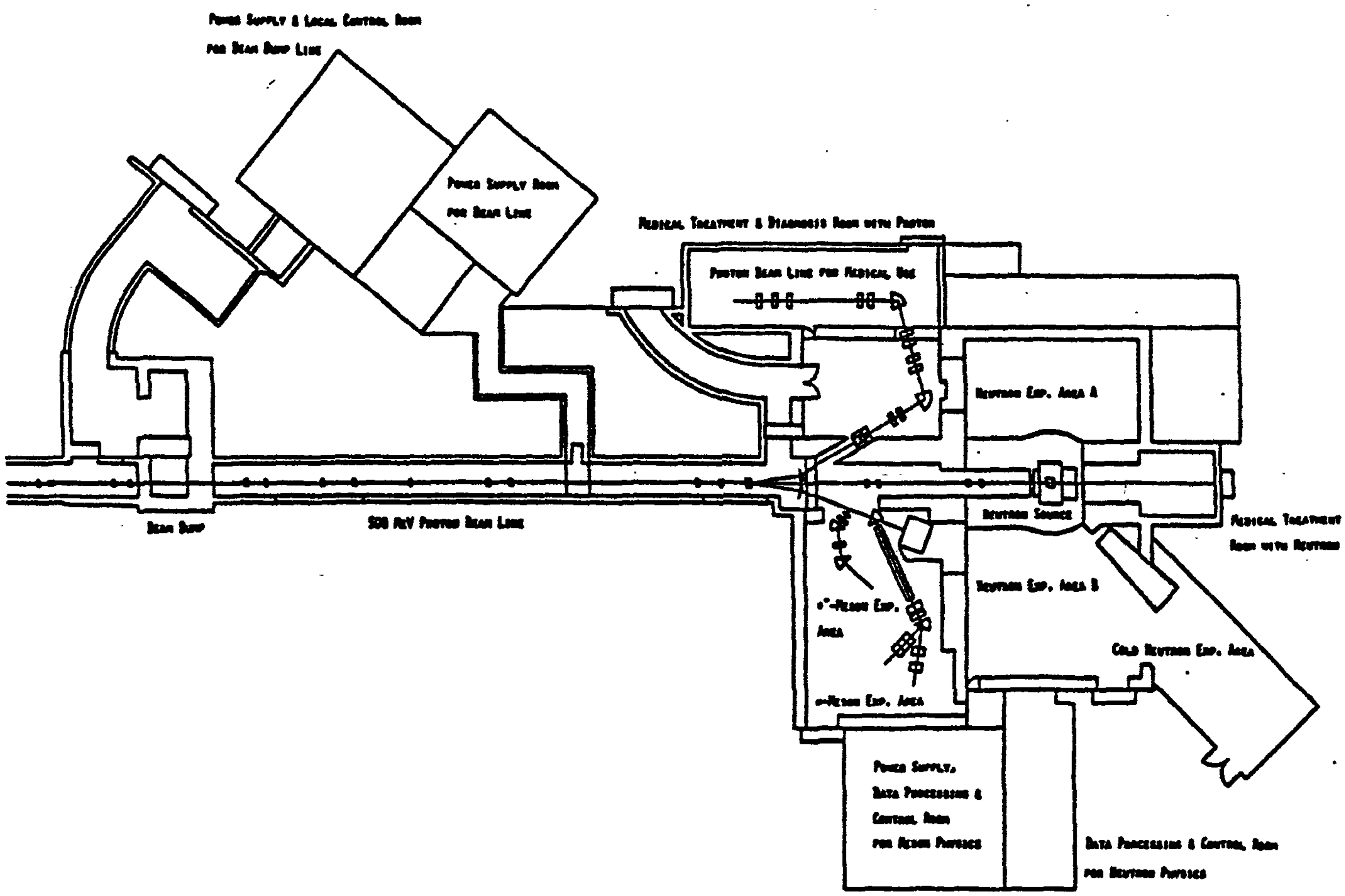

Fig. I-C.1. Layout of the KEK experimental facilities.

D. The Status of LAMPF, D. C. Hagerman, LASL

The Los Alamos Meson Physics Facility (LAMPF) is described in the literature[1] and at this time is in many ways a mature facility serving as a major experimental tool in a variety of scientific investigations. Typically, during production operation of the facility, nine to twelve different experimental groups are using one of the meson, neutron, or proton beams for their research; this simultaneous use by many different groups is one of the most important features of the facility.

During a typical year, at least 4000 h of operation for research is scheduled; both H^+ and H^- beams are available and the H^- beam can be polarized, if desired. During production operation, beam availability is typically in excess of 80%. Beam quality in the machine is very good in that beam spill is quite low even at average currents exceeding 500 μA. It appears that it is quite feasible to provide H^+ beams of 1-mA average current whenever they are needed. High-intensity H^- beams will also be possible assuming development of a suitable ion source.

The thermal and induced-radioactivity problems in the experimental areas associated with the intense beams are difficult to solve. The total power in the beam at a production current of 500 μA is 400 kW; this power is dissipated in and near the targets and the beam stop. At each of these locations the induced activity levels can easily be in the several thousands R/h range. Clearly, repair and modification work in such an environment must be done remotely which requires at least 10 times longer than "hands-on" work. Solution of beam-related problems in the experimental area will determine the pace of further increases in production current.

Future development work on the facility will emphasize increased flexibility of operation as well as increased current. Time sharing with the WNR has been a successful mode of operation; a time-sharing scheme to provide variable energy H^- beam for nucleon-nucleon studies will be implemented within the next year. A high-intensity H^- beam will be added for the WNR proton-storage ring within a few years time. The machine duty factor will be increased so that all users may receive an adequate amount of beam time.

References

1. IEEE Trans. on Nucl. Sci., NS-24, No. 3, pp. 1605-1610, June 1977.

E. Status of the WNR, G. J. Russell, LASL

1. General

There are a number of stages any facility passes through before it reaches a mature state. These evolutionary phases may be broadly represented by: a) conceptual design, b) detailed design, c) construction, d) shakedown/initial operation at low-power, e) routine production at high-power, and f) development. I would categorize the present status of the Weapons Neutron Research Facility (WNR) to be that of approaching routine production operation (with an initial target and target/moderator configuration) and entering into an upgrade/development phase.

The WNR is one of several experimental facilities at the Clinton P. Anderson Meson Physics Facility (LAMPF), see Fig. I-E.1; the layout of the WNR is illustrated in Fig. I-E.2. The high-current area (target 1) is capable of accepting up to 20 μA of proton beam. The high-current target is vertical, surrounded by a cylindrical void ~2-m diam by ~2-m high, and is shielded by a laminated iron-concrete structure ~3.7-m thick. There are 12 flight paths penetrating the target 1 shield, and the moderator surface viewed by a flight path can be set at any angle to any one flight path. Eight of the 12 flight paths are aligned with the target center while the remaining 4 are offset from the target center by an average of 7.2 cm. The low-current target area (target 2) employs a horizontal target and can accept up to 0.1 μA of proton beam or be utilized for measurements with neutrons from target 1. There are 11 flight paths penetrating the target 2 shield.

Proton beam has been brought into target 1 and to the end of the WNR beam channel for use by experiments. The proton beam line into target 2 will be implemented this fall.

A summary of the (design) proton-pulse characteristics for the WNR is given in Table I. As can be seen, the width of the WNR proton pulse is variable. The WNR Proton Storage Ring (PSR) will be capable of providing additional pulse-width and repetition-rate combinations with higher instantaneous intensity. Only the extremes of the PSR operating characteristics are given in Table I.

2. Proton-Beam Line

The WNR beam line is housed in a reinforced concrete beam channel that connects LAMPF to the WNR, a distance of ~ 232 m. The beam line consists of a 10.2-cm diam evacuated beam pipe (when going through magnets the beam pipe decreases to a minimum of 5.1-cm diam), an array of magnets (used to bend, focus, and steer the proton beam), vacuum pumps, and beam-diagnostic equipment.

The WNR proton pulse is prepared for insertion into the WNR beam line by a chopper located in the main LAMPF beam line where the proton energy is 750 keV. The WNR pulse is formed by placing a known spacing (in time) between the LAMPF and WNR pulse (see Fig. I-E.3). This is accomplished by deflecting a portion of the LAMPF pulse into catcher plates at the chopper location and then allowing the protons comprising the WNR pulse to be accelerated to 800 MeV along with the primary LAMPF beam. The chopper can select individual micropulses out of the LAMPF macropulse if required.

The chopper is operated in conjunction with either of two kicker magnets (located in the LAMPF beam line) which deflect the WNR pulse into the WNR beam line. The slow kicker has the capability of deflecting entire LAMPF macropulses (500-μs duration) into the WNR beam line and can be operated from 1-12 Hz. The fast kicker operates at 120 Hz and can presently deflect 5 μs of proton beam into the WNR beam line. The combination of the chopper and kickers allows for a variety of WNR proton-pulse widths at an assortment of repetition rates. Five microsecond proton pulses containing ~ 2×10^{11} protons have been achieved at a repetition rate of 120 Hz. Single micropulse operation (proton pulse widths of 0.16 ns) is possible at an effective rate of 6,000 Hz.

3. High Current Target

The design of the WNR target and target/moderator configurations for target 1 was strongly influenced by the need to produce neutrons with energies ranging from a few meV to several hundred MeV having pulse widths as narrow as practical. A bare target is used to produce neutrons with energies $\gtrsim$ 100 keV. Neutrons with energies < 100 keV are produced by surrounding the target with a suitable moderator. The existing WNR target/moderator configuration is a tightly coupled system[1] and is shown in Fig. I-E.4.

The target and moderators (and associated mechanical mechanisms) as well as the various cooling systems have proven to be extremely reliable over the past year of "more-or-less" routine operation. There has been essentially no loss in the WNR operation over the last year which is directly associated with target 1 not being ready to accept protons. To date, the Ta target has been subjected to approximately 2,300 μA·h of 800-MeV proton bombardment. The target system has recently been operated for a short period of time at an average proton current of 18 μA.

4. Experiments and Experimental Data

There have been some measurements made to characterize the neutronics of the high-current target and moderators, and some basic measurements made to obtain data for computer code validation. These experiments include:

- neutron-spectrum measurements at 90° to the Ta (high-current) target covering the energy range from ~ 0.5 MeV to ≈ 200 MeV
- thermal neutron spectrum measurements from an H_2O moderator
- absolute spatial distributions of thermal, epithermal, and fast-neutron surface fluxes from an H_2O moderator
- absolute measurements of thin-target neutron spectra from ~ 0.5 MeV to ~ 800 MeV as a function of angle and material
- absolute measurement of neutron production from thick targets.

Some preliminary results[2] of neutron spectra from the high-current Ta target and the H_2O moderators are shown in Figs. I.E-5 and I.E-6. Some initial results of measured spatial distributions of thermal, epithermal, and fast-neutron surface fluxes from the high-current H_2O moderator are shown in Fig. I-E.7 and I-E.8. Computations are being performed to compare with the measured distributions. Thin-target neutron spectrum measurements using Al, Cu, In, Pb, and U targets are under way to validate basic production processes incorporated in the Monte Carlo codes used in spallation neutron source design. These measurements are being done by S. D. Howe and cover the energy range from ~ 0.5 MeV to ~ 800 MeV at angles of 0°, 30°, 45°, and 112°. Some initial data at 45° are shown in Fig. I-E.9. Absolute neutron yields from targets of Pb, Th, and depleted U have been measured; preliminary results are given in Table II and compared with some earlier measurements (where possible) and initial calculations.

The arrangement of target 1 flight paths and the initial instruments being developed on them are shown in Fig. I-E.10. The instruments and flight-path location will change as target 1 is further developed.

5. Near-Term Developments at the WNR

The following facility-type developments will be undertaken within the next year:

- replace the Ta target with W, improve the H_2O moderator canister construction, and alter the method of target/moderator attachment to the target/moderator mechanisms to improve remote handling capability
- develop proton-beam diagnostics for target 1 and improve beam-spot quality
- develop a facility neutron monitor
- implement a cold moderator
- optimize the production of both high-energy and low-energy neutrons
- reduce experimental backgrounds due to γ-rays, neutrons, and protons
- increase simultaneous utilization of flight paths for target 1 and study the feasibility of incorporating a radiation damage capability into target 1 by reconfiguring the target/moderator system
- improve fast-kicker reliability and capability
- implement target 1 remote handling
- develop more long-flight paths for target 1
- develop a "universal" target 1 shutter/collimation system
- expand data acquisition/reduction capabilities
- add flexibility to chopper system to allow time-sharing of proton beams.

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2. G. J. Russell, P. W. Lisowski, and N. S. P. King, "The WNR Facility - A Pulsed Neutron Source at the Los Alamos Scientific Laboratory," Int'l. Conf. on Neutron Phys. and Nucl. Data for Reactors and Other Applied Purposes, Harwell, England, September 25-29, 1978.

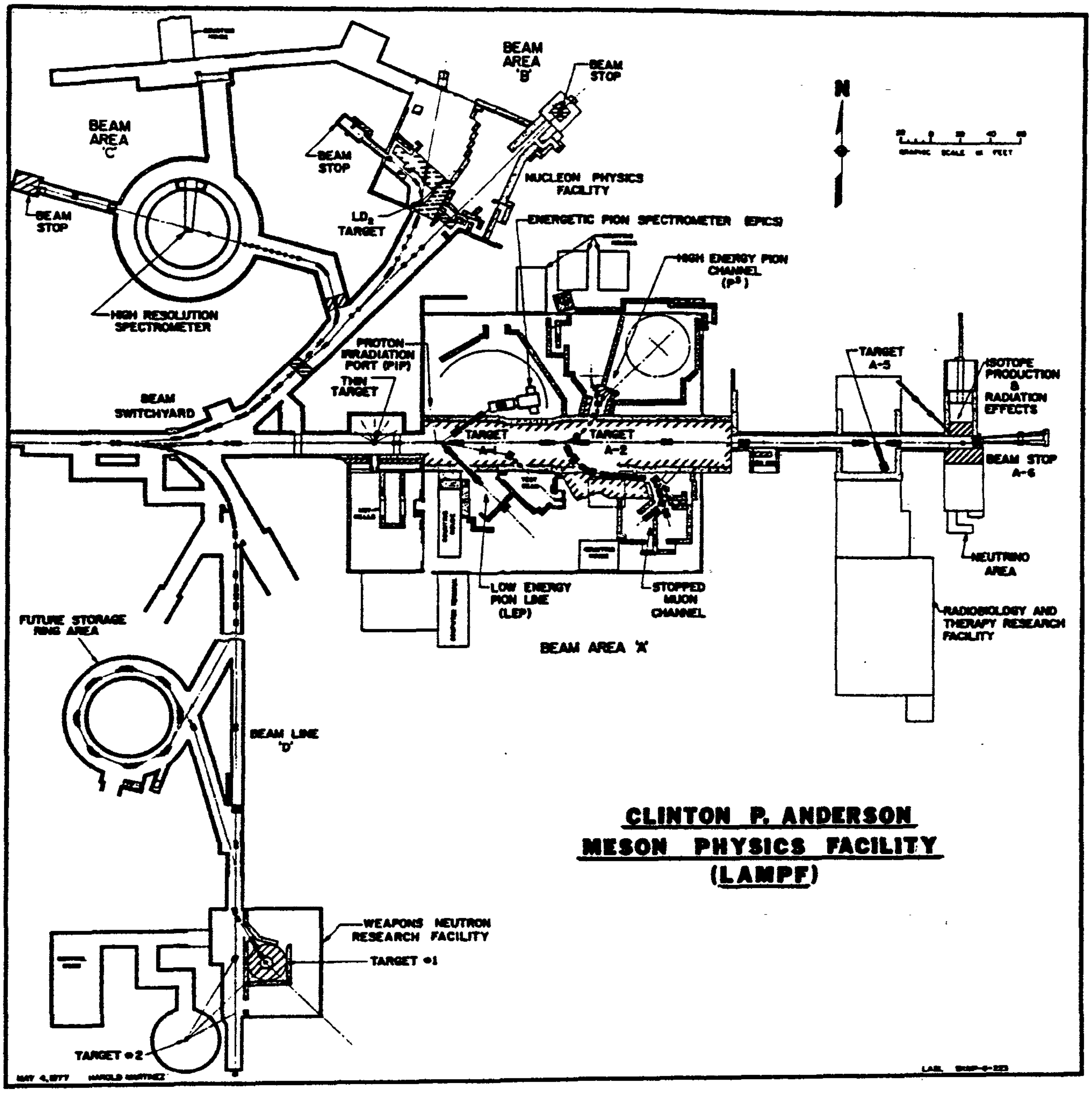


Fig. I-E.1. Experimental areas at LAMPF showing the WNR in the lower left corner.

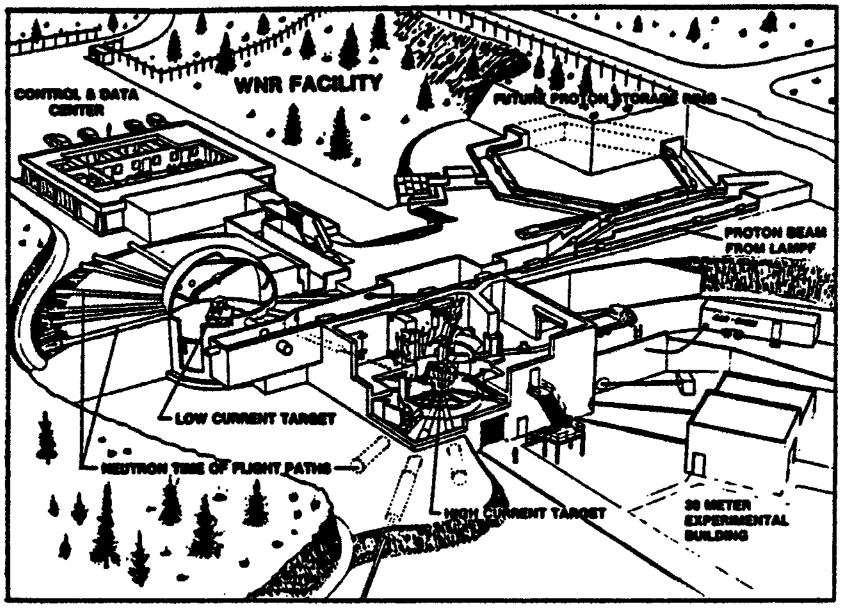


Fig. I-E.2. Illustration of the WNR.

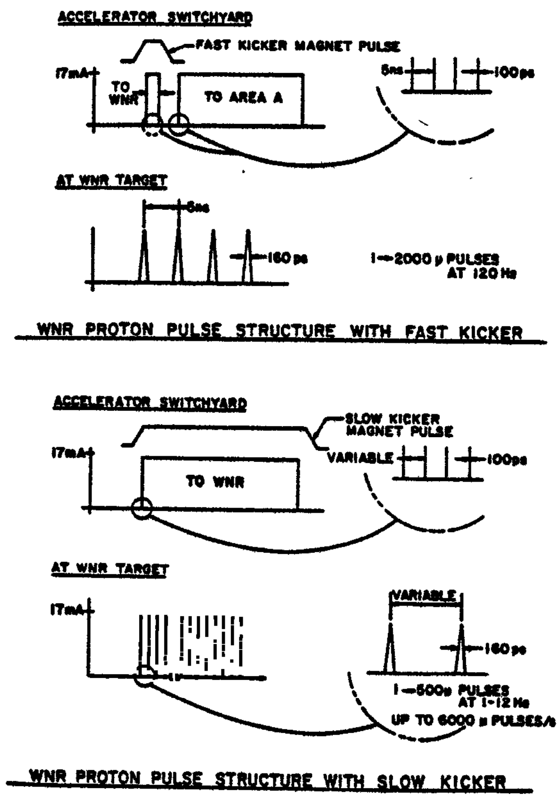
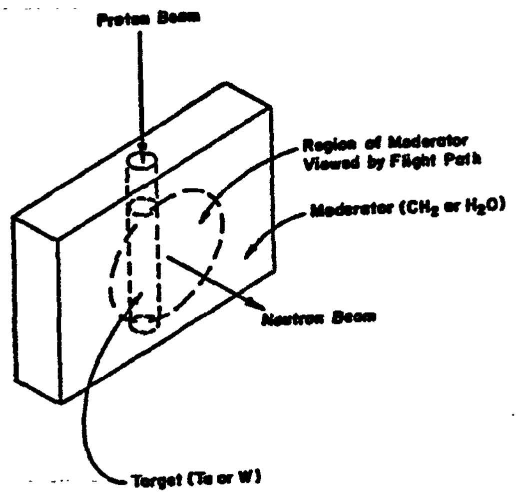


Fig. I-E.3. Illustration of the WNR proton-pulse preparation.



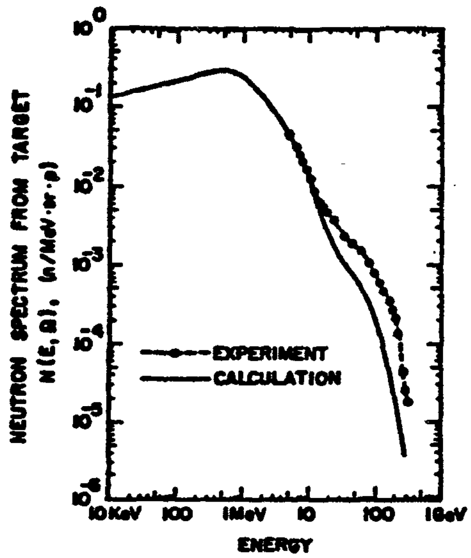


Fig. I-E.4. The initial WNR target/moderator configuration. The top of the target is below the top of the moderator.

Fig. I-E.5. Fast-neutron spectrum (at 90° to the proton-beam axis) emitted from the cylindrical surface of the WNR Ta target.

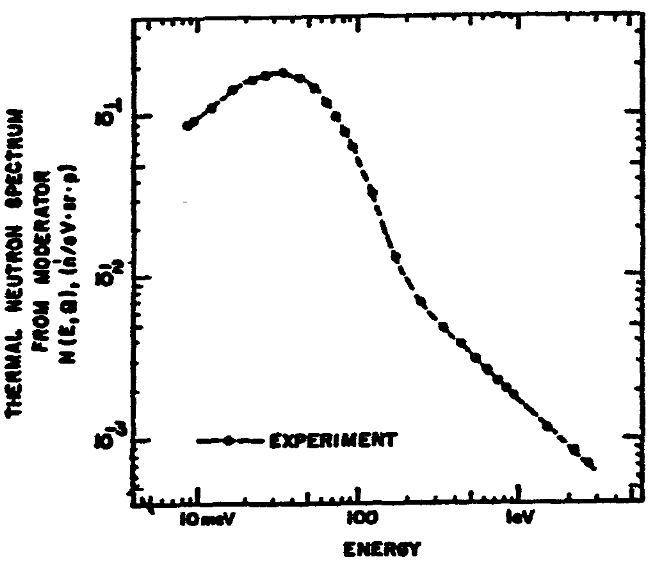


Fig. I-E.6. Thermal-neutron spectrum (at 90° to the proton-beam axis) emitted from an unpoisoned H_2O moderator.

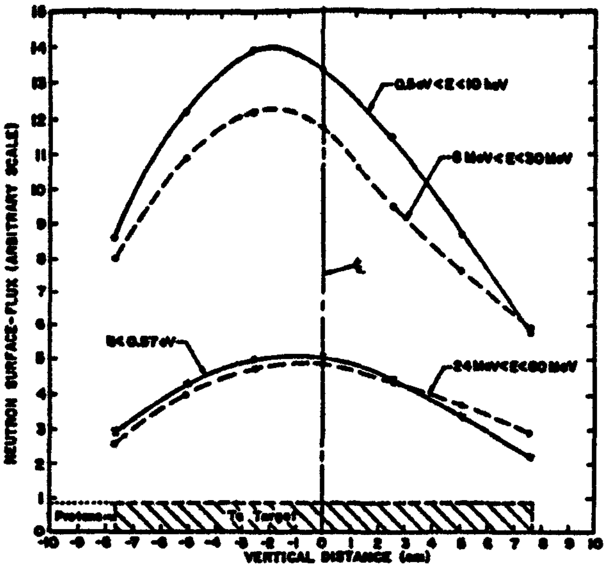


Fig. I-E.7. Measured vertical distributions of the neutron-surface flux from the 20-cm by 30-cm surface of the WNR H_2O moderator. The measurements were made along the axis of the target.

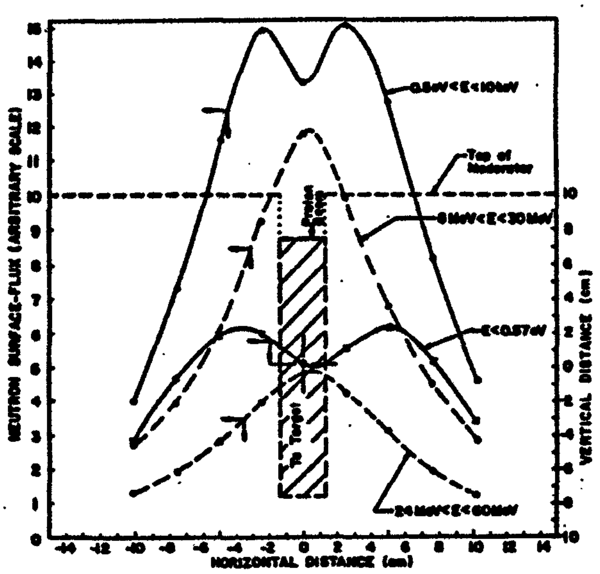


Fig. I.E-8. Measured horizontal distributions of the neutron-surface flux from the 20-cm by 30-cm surface of the WNR H_2O moderator. The measurements were made along the moderator centerline. The left axis shows the neutron surface flux and the right axis shows the vertical size of the target/moderator configuration.

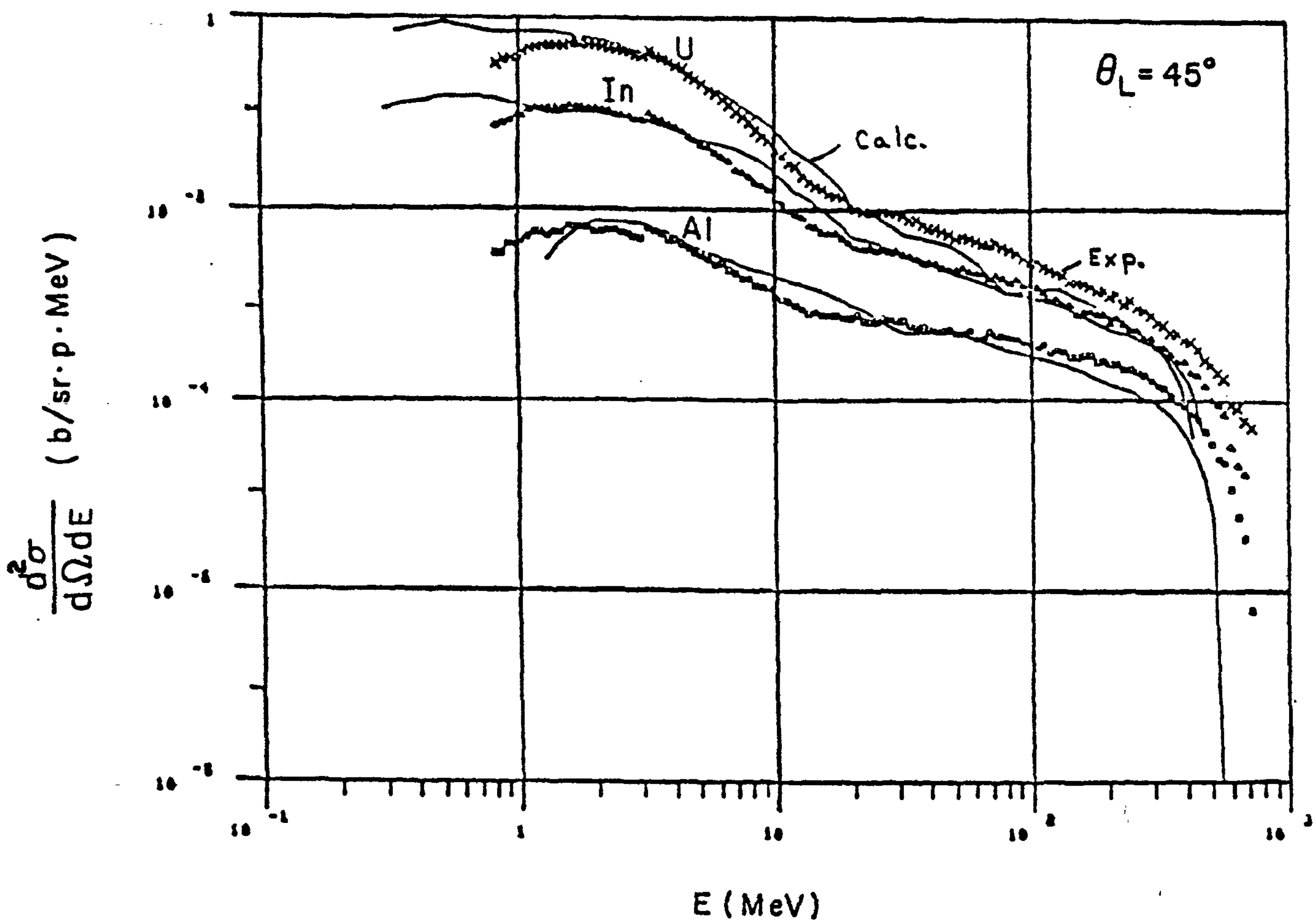


Fig. I-E.9. Neutron spectra measurements from thin targets bombarded by 800-Mev protons. The data are expressed as double differential cross sections.

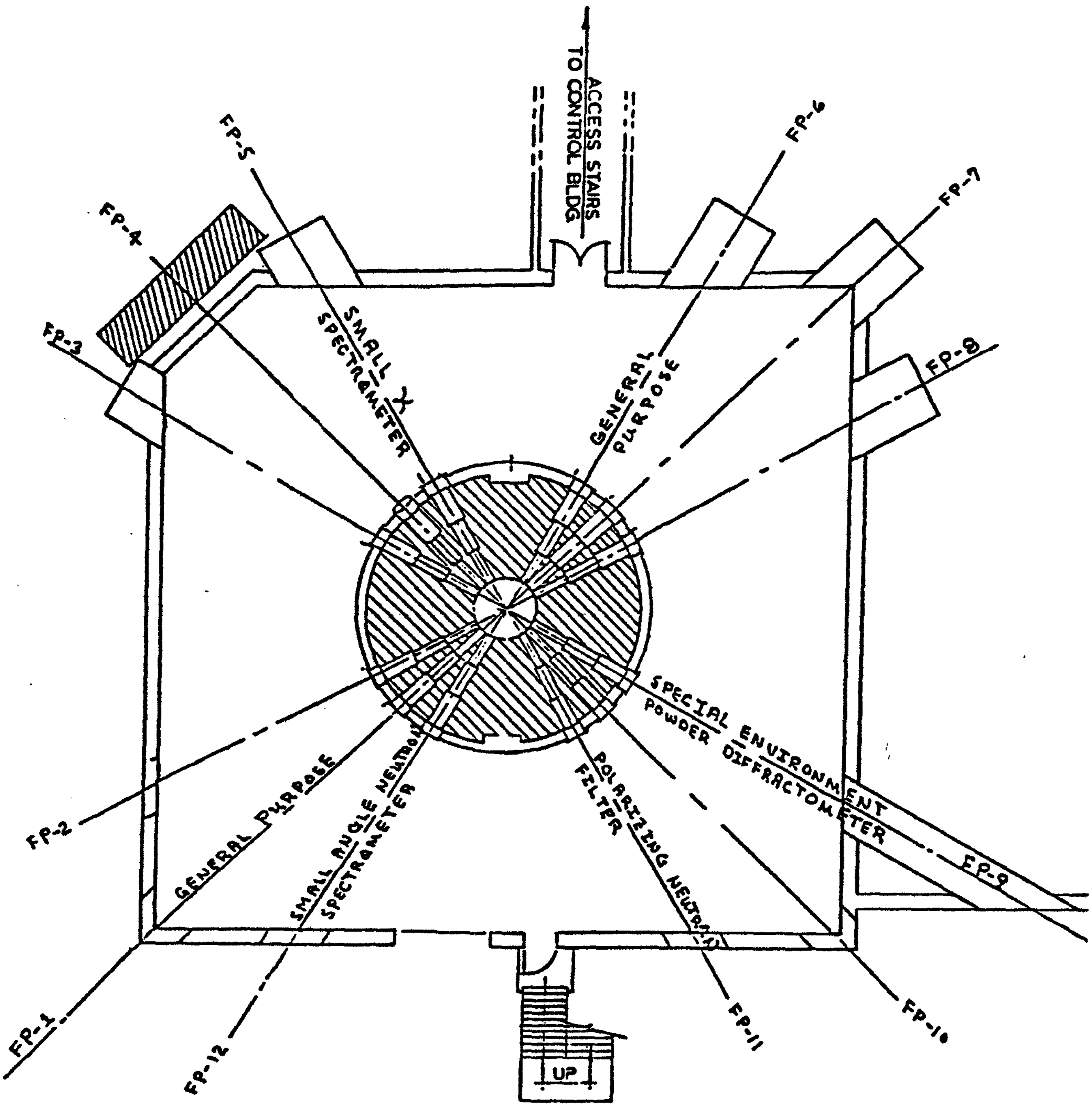


Fig. I-E.10. Initial flight-path utilization for target 1 at the WNR.

TABLE I

LAMPF AND WNR PROTON BEAM DESIGN CHARACTERISTICS

	LAMPF[a]	WNR		WNR + PSR	
		Micropulse[b] Mode	Macropulse[c] Mode	Low Repetition Rate Mode	High Repetition Rate Mode
Pulse Width	500 μs	160 ps	10 μs	200 ns	1 ns
Protons/pulse	5×10^{13}	5×10^{8}	1×10^{12}	5×10^{13}	1×10^{11}
Repetition Rate	120 Hz	1-6000 Hz	120 Hz	2.4 Hz	720 Hz
Protons/s av	6×10^{15}	$5 \times 10^{8} - 3 \times 10^{12}$	1.2×10^{14}	1.2×10^{14}	7.2×10^{13}
Average Current	1 mA	0.08 nA - 0.5 μA	20 μA	20 μA	12 μA

a The LAMPF beam structure contains micropulses separated by 5 ns intervals and grouped in 500-μs-long macropulses at 120 Hz for a 6% duty factor.

b Individual LAMPF micropulses form the WNR pulse.

c Multiple LAMPF micropulses comprise the WNR pulse. In the macropulse mode, a variety of pulse width and repetition rate combinations are possible; only the longest pulse width at the highest repetition rate is illustrated.

TABLE II

PRELIMINARY LASL FERFICON[a] RESULTS
COMPARED TO EXTRAPOLATED BNL COSMOTRON DATA

Proton Energy (MeV)	Target Material	LASL Target Size diam x length (cm x cm)	LASL FERFICON		BNL COSMOTRON H_2O Captures/Proton		BNL COSMOTRON Target Size diam x length (cm x cm)
			Calculated Neutron Leakage[c] (n/p)	Measured Thermal Neutron Captures/Proton	Calculated	Measured	
800	Pb	9.85 x 40.7	17.1	13.0	15.8	13.4	10.2 x 61.0
800	U	10.0 x 40.7	26.9	25.3	23.2	26.1	10.2 x 61.0
800	Th	18.3[b] x 40.7	21.9	17.1	----	----	-----
800	U	19.3[b] x 40.7	30.2	28.8	----	----	-----

[a] FERFICON stands for Fertile-to-Fissile Conversion.
[b] Effective target diameter.
[c] Includes neutrons of all energies leaking from a bare target.

F. The Proton Storage Ring Project at the WNR, G. P. Lawrence, LASL

The Proton Storage Ring (PSR) at LAMPF is a device which will provide very large pulse-intensity increases (100 to 1000 times) to the Weapons Neutron Research Facility (WNR), as well as an enhanced repetition-rate capability. The PSR acts as a pulse compressor, converting long-proton bursts from the accelerator into very short but very intense bunches. This capability enables many more neutrons to be generated in the WNR target with pulse lengths suitable for time-of-flight measurements, and also enables experimenters working with different neutron energies to use the facility simultaneously. After completion, scheduled for 1984, the PSR addition to the WNR will make this facility the premier pulsed neutron source in the world over an exceptionally wide-energy range (thermal to several hundred MeV).

At the beginning of calender year 1979, the PSR appeared as a $16.7 M line item construction request in the fiscal 1979 budget, and received Congressional approval at that level. However, as a result of discussions between LASL and DOE, the project design has been recently upgraded to permit operation at average currents of 100 μA, five times greater than previously planned, and to allow the option of running at even higher (up to 400 μA) currents in the future. The upgrade, which consists mainly of a larger aperture magnet system and a larger underground tunnel to house the Ring, brings the total project cost to $21.1 M. It is expected that $2.0 M will be released in FY-1979 to support detailed design and engineering of buildings and equipment. The higher average proton current that the upgraded design will provide makes possible a greatly expanded materials science program at the WNR using thermal-neutron scattering.

The PSR is being designed for flexible, multimode operation. It will use state-of-the-art accelerator technology, including the recently developed method of continuous-beam injection using the stripping of H^- ions. Figure I.F-1 is an artist's conception of the project. In the illustration, one sees the three major structures associated with the PSR project. In the center foreground is the Ring itself, which is placed in a 5-m by 5-m underground tunnel about 100 m in circumference. Located above the Ring is a service building, which houses power supplies and other support equipment. A laboratory support and staging building is located adjacent to the Ring. The PSR design features 10 identical focusing and bending cells, characterized by magnets having 15-cm vertical apertures and 12 kG fields, and incorporates systems for H^- stripping injection, rf bunching in two operating modes, ultra-fast extraction, and instability detection and suppression. Conceptual design of the structures and Ring equipment systems has undergone steady evolution during the last year. The theory of PSR operation has also been the object of considerable effort throughout the year.

The project involves an extensive component research and development effort, which can itself be expected to further the technology of storage or accumulator rings. This program was initiated in 1978. Work has begun on development of the extraction kicker charging system, fast feedback instability control system, the first harmonic rf bunching system, and the beam position monitoring system. In addition, vacuum components are being tested and a beam induced electron multipactoring experiment is being set up.

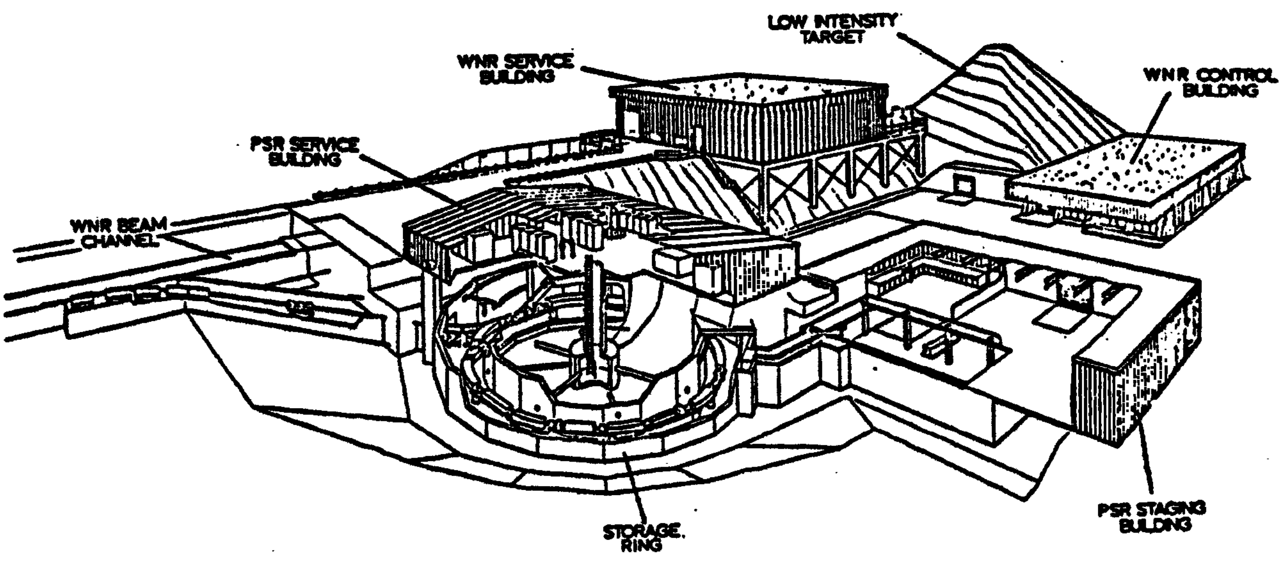


Fig. I-F.1. Proton storage ring location at the WNR.

G. High-Current Accelerators for Fissile-Fuel Production, J. S. Fraser, CRNL

For many years, Canada has maintained a modest program designed to develop accelerator-breeder technology as an adjunct to the nuclear power fuel cycle. Our long-range objective is to develop an alternative scheme to extend the usefulness of uranium and thorium resources. At the present time, electronuclear breeding is not economically attractive, but the time may well come when the cost of uranium rises to say, \$300/kg (in 1979 dollars). When and if that happens, the accelerator breeder will have an economic attraction. In the meantime we plan to develop the accelerator and, to some extent, the target technologies so that they are available if needed.

The idea of accelerator-produced neutrons for fissile-material production is not new. An extensive development program on the MTA[1] accelerator was undertaken in the USA in the early 1950's to produce plutonium[2,3] but was terminated when sufficient uranium ore was found in Colorado to supply the Savannah River reactors. A 500-MeV, 320-mA, 50-MHz deuteron accelerator, with a primary beryllim target surrounded by a secondary depleted uranium target, was expected to produce about 500 kg of plutonium a year at \$124/g (~\$300/g, 1976 \$). The concept of bombarding a heavy element target with energetic nucleons was also recognized by W. B. Lewis[4] at Chalk River around 1950. Lewis made some remarkably foresighted comments on the role accelerators might play in a nuclear energy system.

Canadian interest in spallation-neutron sources continued through the 1950's with measurements at the McGill cyclotron[5] and using cosmic ray neutrons.[6] The Intense Neutron Generator (ING) study[7,8] at CRNL was based on the concept of a high-power proton beam bombarding a liquid lead-bismuth eutectic target; its goal was the production of a high flux of thermal neutrons.

Although the ING study was terminated as a program for a scientific research facility, a small effort continued on the industrial application of accelerators for production of nuclear fuels.[9] The work was concentrated on two low-energy, high-current, 100% duty-factor accelerator experiments[10,11] and a study of efficient radio-frequency generators.

An economically competitive accelerator breeder would require a beam power of the order of 300 MW, typically a beam current of 300 mA at 1 GeV. This high-current level has been achieved in proton linacs - the high power is a consequence of extending the duty factor to 100%. It is precisely for that reason that we are carrying out several low-energy, high-current, cw accelerator experiments.

The first of these experiments is a low-energy proton linear accelerator designed to accelerate protons up to 3 MeV. The starting point is a duoplasmatron ion source for protons located in the terminal of a high-voltage set, a standard Cockcroft-Walton accelerator operated as a dc terminal. The ion source has delivered a dc proton current in excess of 100 mA with normalized emittance of 3.2 $\pi \cdot$mm$\cdot$mrad. This is a good quality beam. The beam is accelerated to 750 keV in a high-gradient column. It is then injected into a 3 MeV Alvarez accelerator tank. The ion source and high-gradient column have been operated successfully up to 45 mA.

Beam experiments are about to begin. These experiments will give us experience in the operation of a high-current injector and in the most difficult stages of the low-energy part of the breeder accelerator. In many aspects of this work we are opening up new ground. With the Alvarez structure itself we hope to gain information on the space-charge limits of operation of such a structure.

While the present dc injector is suitable for initial beam experiments in the Alvarez, advanced injector concepts will be tested separately in an injector-test experiment. This will include a duoPIGatron, cusp or picket-fence source, mass anlysis and differential pumping in the high-voltage terminal and ceramic insulators well shielded from bremsstrahlung. Currently we have a duoPIGatron operating at over 450 mA total current with a normalized emittance of about 10π.mm.mrad.

Like other intermediate-energy accelerators, the breeder accelerator would make a transition at, say, 100-150 MeV, to a different kind of structure which would be more efficient at higher energies, probably a biperiodic wave guide structure similar to the 800-MeV linac at Los Alamos. We have built an electron analog of this structure designed to carry out experiments on the field-level control under full-beam loading, the cooling of the structure, the operation of the safety, and beam-control devices all at 100% duty factor. It consists of a three-element electron gun, a buncher cavity, a graded-β pre-accelerator tank, and one main accelerator tank. The bunched and the graded-β tank have been operated successfully up to 20 mA and both tanks at 16 mA without difficulty. We have demonstrated that the structures and the control systems work well at the design level of power density and at 100% duty factor. Computer control of a cold start to beam ready condition in 10 min has been demonstrated.

For several years we have also carried out some target studies, including calculations and experiments. The calculations have been limited to simple geometries amenable to experimental verification. In the future we intend to tackle more complex assemblies which come a little closer to engineering reality.

The experimental program of measurements, called "FERFICON" for "fertile-to-fissile conversion," is currently under way at the TRIUMF cyclotron in Vancouver. These experiments are designed not only to verify earlier measurements on neutron production but to obtain data on fertile-to-fissile conversion rates.

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10. B. G. Chidley, et. al., "The Chalk River High Current Test Facility," Proc. 1972 Prot. Lin. Accel. Conf., Los Alamos, NM, LA-5115 (1972) p. 218.

11. J. S. Fraser, et. al., "The Chalk River Electron Test Accelerator," ibid., p. 226.

H. The TRIUMF Thermal Neutron Facility, I. M. Thorson, TRIUMF

The primary purpose of the TRIUMF Thermal Neutron Facility (TNF) is to stop the residual proton-beam downstream of the meson production targets in the main TRIUMF beamline. The nominal full current from the 500-MeV isochronous cyclotron is 100 μA; as much as 35% of this beam current is removed by the meson production targets. The remaining beam is used to produce a steady-state neutron source in a 13-cm-diam by 25-cm-long lead target of ~ 3×10^{15} n/s^{-1}, giving thermal flux levels of ~ 3×10^{12} $cm^{-2} \cdot s^{-1}$ in the surrounding H_2O and D_2O moderators. The target heat is dissipated by convection of the molten lead and nucleate water boiling at the outside of the 0.3-cm-thick stainless steel container.

The TNF is intended for use as both a neutron-beam and irradiation facility with hardware provisions for both having been installed. Two of the four neutron-beam tubes view the D_2O moderator below the lead target offset 15 cm from target centerline and at angles to the incident proton beam of 60° and 120°. The other two are offset by 30 cm from the target centerline and form a through-tube at the interface between the D_2O moderator and H_2O reflector. The access to the D_2O moderator compartment is through a 5-cm by 13-cm vertical tube from the top of the 45-cm diam by ~350-cm high H_2O moderator coolant column.

The thermal and epithermal neutron-flux distribution in the D_2O moderator has been measured by activation of gold foils, with integral proton-beam current estimated from the ^{24}Na activity induced in a thin aluminum foil mounted directly ahead of the target. The results are shown on the lateral cross-section view of the assembly in Fig. I.H-1. Measurements were also made with H_2O in the D_2O moderator tank. The comparison of these experimental results with previous calculations using the multigroup reactor code EXTERMINATOR presuming a zircalloy target canister and more recent ones for the stainless steel canister actually used, are shown in Table I. A tentative explanation for the wider distribution of thermal flux in the H_2O case and the lower flux in D_2O moderator is a harder original neutron spectrum than the fission spectrum assumed in the calculations.

The worst problem encountered during commissioning of the TNF was the evolution of radioactive mercury species from the evacuated expansion space at the top of the lead target (when the target is operated above the lead melting temperature). The saturated mercury activities of all species from mass 206 to 188 for continuous operation with a 100 μA, 500-MeV proton beam is estimated to be ~ 3 kCi. Most of the species involved have half lives of 10's of hours or less; two high yield exceptions are ^{195}Hg whose daughter ^{195}Au has a half life of 183 days and represents ~ 25% of the saturated activity inventory and ^{194}Hg with a half life of 1.3 years and ~ 10% of the total yield. Because we value the comprehensive target canister integrity monitoring capability that the vacuum condition provides, we have implemented a liquid nitrogen temperature cold trap to remove the mercury species ahead of the mechanical vacuum pump. The output of the pump is exhausted to one of two holding tanks to allow the noble gas species to decay before release to the atmosphere. Only very rough experimental measurements of the active species produced in the target have been possible so far because of the complications imposed by fluctuating proton beam intensities. As soon as steady-beam current conditions are available for extended periods, measurements will be made to confirm the empirical production cross-section values used in making the activity estimates cited above and to establish the evolution times from the molten target.

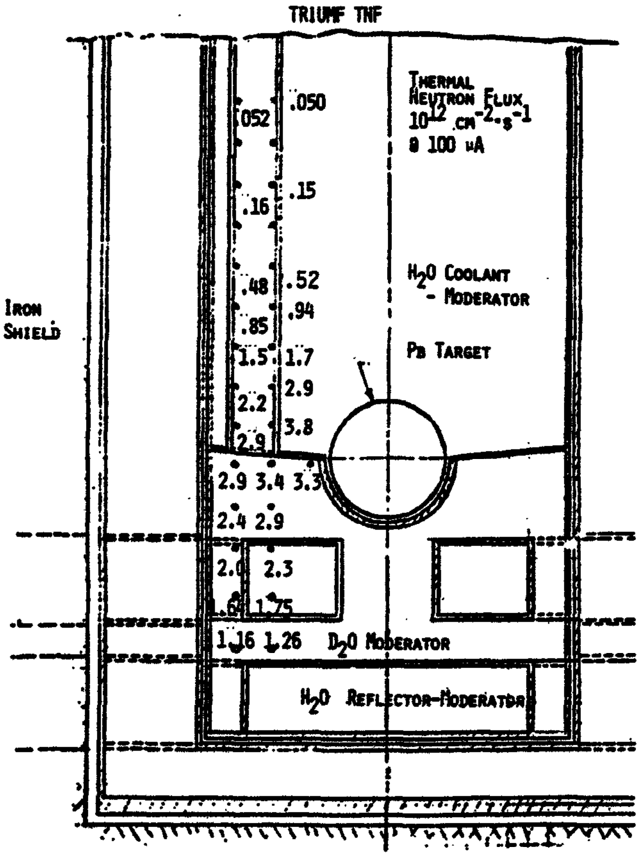


Fig. I.H-1. Measured thermal and epithermal neutron flux distributions with D_2O moderator.

TABLE I

TNF THERMAL NEUTRON FLUX

(10^{12} cm^{-2}· s^{-1} @ 100 µA)

r(cm)	Calculated				Experimental	
	Al Target Can		SS Target Can		SS Target Can	
	H_2O	D_2O	H_2O	D_2O	H_2O	D_2O
11	6.6	6.6	6.2	5.1	5.5	3.3
16	2.1	6.3	2.0	4.6	4.4	3.4
21	0.56	5.1	0.55	3.9	2.1	2.9

I. The SIN Neutron Source, W. E. Fischer, SIN

1. General

During the year 1978, the idea of a spallation neutron source at SIN has been consolidated into an already fairly specified concept.[1] As a result of the symposium on applications of such neutron sources held at SIN (April 1978), we came to the conclusion that a continuous version exploits the capabilities of the SIN accelerator system optimally. Furthermore, this mode would provide for the users in Europe a complementary neutron source to the planned pulsed SNS device at the Rutherford Laboratory.

2. Physics of the Target

a. Neutron Yield

The average energy deposited by the cascade process as excitation energy in the nuclei of a lead target is roughly 100 MeV per nucleus. The primary proton energy is assumed to be 600 MeV. According to the thermodynamical nuclear model such an excited nucleus evaporates about eight neutrons. Including the contribution from spallation reactions of the second generation in the cascade inside a thick target, we obtain a source strength of about ten evaporation neutrons per incident proton. With a primary beam of 600-MeV protons with 1 mA beam current this corresponds to a source strength of 6×10^{16} n/s.

b. Energy Consideration

The beam power for a 1-mA, 600-MeV proton beam is 600 kW. By nuclear recoils and ionization the cascade-reaction deposits about 450 kW in the target with 125 kW being carried from the target by escaping cascade and evaporation neutrons. The missing 25 kW are used in breaking up the target nuclei - these cascade reactions being, contrary to nuclear fission, endothermal. These considerations, together with the yield discussed above, lead to a fairly low-energy deposition per useful neutron produced.

For a Pb/Bi target we have to deal with a heat deposition of 40 MeV/n - that is a value which is five times lower compared to neutron production in a nuclear reactor.

c. Activation of the Target

By the spallation reaction, about two to three protons with higher energy are knocked out of the target nucleus. The evaporation process of the residual excited nucleus is dominated by neutron emission. The target activation for a Pb/Bi target is therefore dominated by isotopes of Tℓ, Hg, Au, and evidently Pb and Bi. These isotopes are poor in neutrons and decay by β^+, γ-processes. The radiation from these heavy spallation products is relatively soft compared to the radiation from, e.g., fission products. A large part of the activation energy is therefore absorbed in the target itself. The correspondingly low radiation heating of material around the target region may present a significant advantage for the arrangement of a cold-neutron source in this area.

The saturation activity (β^+ and γ) with a 1 mA primary current is in the region of 1 MCi for a PB/Bi target. By self absorption, this activation leads to a heating power of about 6 kW. The long-term activation is given by the decay of ^{207}Bi with $t_{1/2}$ of ~ 38 yrs.

3. Neutron-Flux Distribution in the Moderator

Fig. I-I.1 shows a possible target/moderator arrangement. Due to the possibility of neutron multiplication by (n,2n) reactions of fast neutrons, as well as for technological reasons, the central part of the moderator around the target consists of Be. The best choice of the external reflector is D_2O due to its low absorption cross section for thermal neutrons. The results of a two-dimensional diffusion calculation with nine energy groups in this system are presented in Fig. I-I.2 and I-I.3. The primary proton beam current considered for this calculation is 1 mA. In the report[1] mentioned above, several modifications of this basic arrangement have been investigated.

4. Technology of the Target

The most attractive version of the concepts investigated consists of a Pb/Bi-eutectic circulated by an electromagnetic pump through a heat exchanger, giving off the heat to a secondary circuit. The main advantages of Pb and Bi for a target material are:

- low absorption cross section for fast and thermal neutrons
- low melting point of the eutectic (123 °C)

The window that is the wall between the eutectic and the vacuum of the proton beam line has to be cooled by heat transported to the liquid metal. The material of the window has to be chosen according to its thermal resistance.

a. Cooling Circuit

In order to obtain some insight into the problems of a Pb/Bi system, an order has been given to Innovent AG, Industrielle Forschung und Entwicklung, Zurich for a conceptual study of the treatment of the heat in a spallation source. According to this report[2] a circuit of the following type emerged (see Fig. I-I.4).

The Pb/Bi circuit including heat exchanger and pump is enclosed in a helium gas system. It provides on the one hand a security enclosure of the radioactive Pb/Bi, and on the other hand it serves as a pre-heating and liquification system for the eutectic. During operation, the Be mantle around the target can also be cooled with this helium gas. After shut down of the beam, the power from the activation of spallation products in the Pb/Bi may be removed by this helium system even in case of a drop of the circulation of the eutectic. The power in the helium system is low (10 to 20 kW) and corresponds to achievements of helium cooling well known at the institute in connection with cooling of special magnets and targets. Helium is relatively weakly activated and can be cooled with water from the tertiary circuit.

The heat exchanger will be cooled by "Dowtherm A" (freezing point 12 °C, boiling point 257 °C). Dowtherm A is an organic (but sufficiently radiation-resistive) liquid used in reactor circuits. As a circulation pump for the Pb/Bi circuit we consider an electromagnetic pump as the best, although most expensive, solution.

b. Target

Figure I-I.5 shows a schematic cut through a cylindrical Pb/Bi target including the Be mantle. The window at the entrance of the beam is made of Mo and optimally cooled by the entering Pb/Bi liquid. Two (pyrolytic graphite) windows with peripheral cooling sufficient for beam currents up to 3 mA have been foreseen upstream of the Mo window. These graphite windows permit a diagnostic during operation (concerning leaks in the main window) by continuous observation (mass spectrometer) of the gas composite between the windows. The disposition is coaxial in order to minimize the thermal stress. The whole system, including the Be part of the reflector forms a compact cylinder, which may easily be exchanged.

c. Layout

For reasons of simplicity and costs we consider a horizontal proton beam line, 1.5 m above ground. Similar arguments lead us to horizontal neutron beam lines, about 30 cm above or below the source in order to reduce the background of direct radiation and fast neutrons from the source. A schematic layout is shown in Fig. I-I.6.

References

1. W. E. Fischer, W. Joho, Ch. Tschalar (SIN); B. Sigg (IRT-ETH); H. Rauch (Atominstitut der Oesterreichischen Hochschulen, Wien), "Studie uber eine Kontinuierliche Spallations-Neutronenquelle am SIN."

2. H. P. Weiss, Innovent AG, Zurich, "Warmehaushalt einer Spallations-Neutronenquelle."

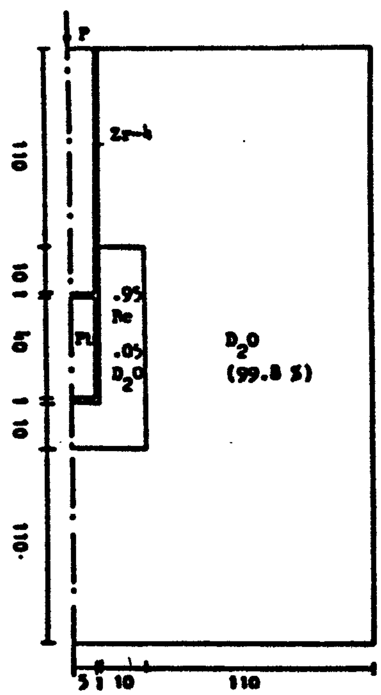


Fig. I-I.1. Geometry of the target/moderator system.

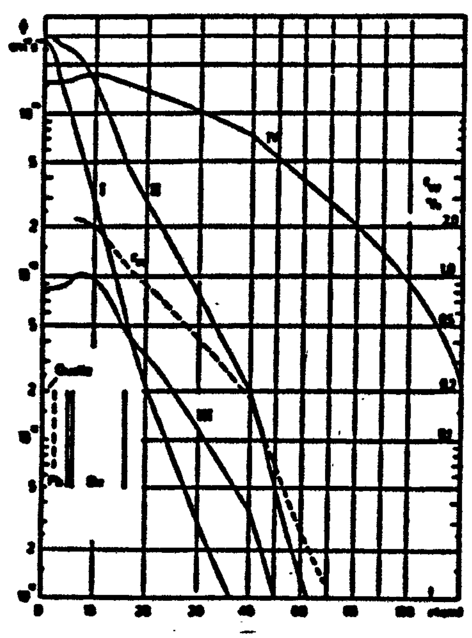


Fig. I-I.2. Radial distribution of the group fluxes and the Westcott-Coefficient.

I: 0.86 MeV ≤ E ≤ 10 MeV
II: 1.5 eV ≤ E ≤ 0.86 MeV
III: 0.14 eV ≤ E ≤ 1.5 eV
IV: E ≤ 0.14 eV (thermal)

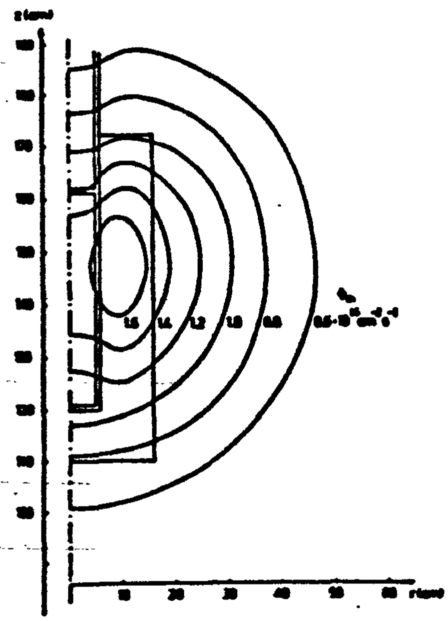


Fig. I-I.3. Flux lines for constant thermal neutron flux.

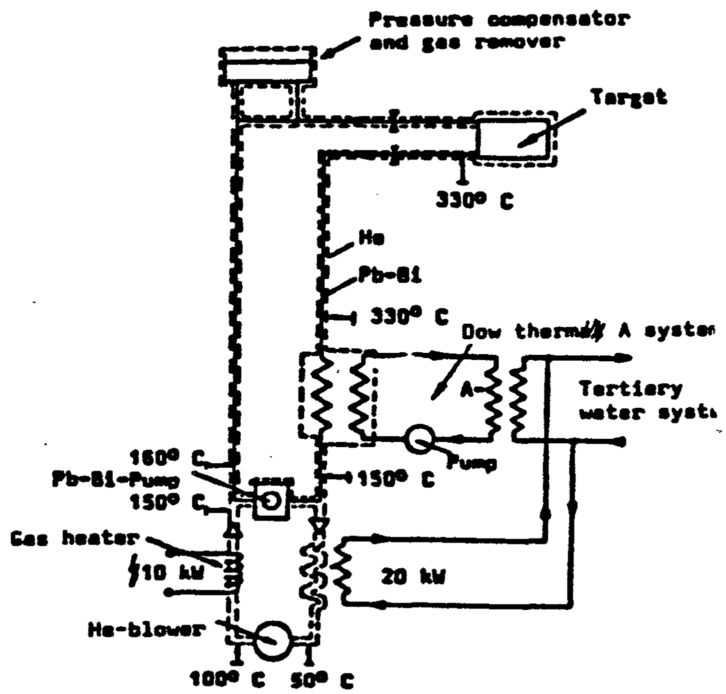


Fig. I-I.4. System of cooling circuits for a Pb/Bi target.

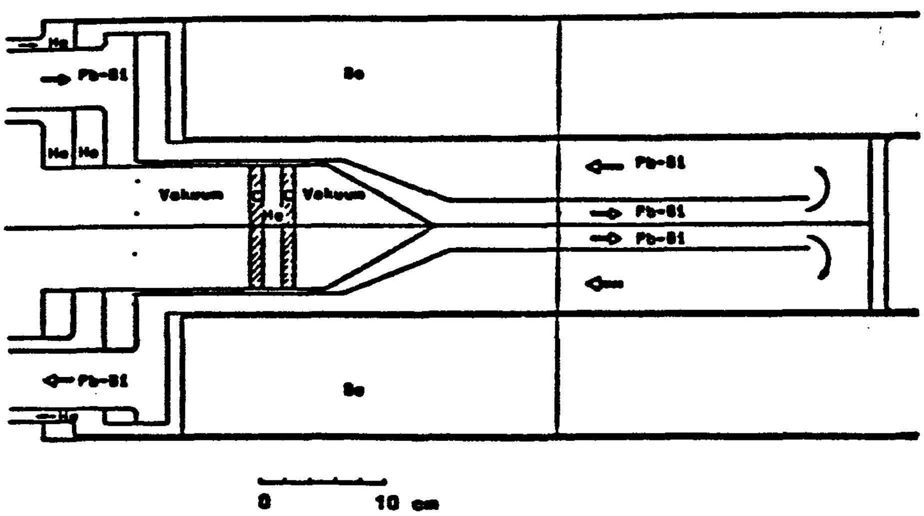


Fig. I-I.5. Section through a Pb/Bi target.

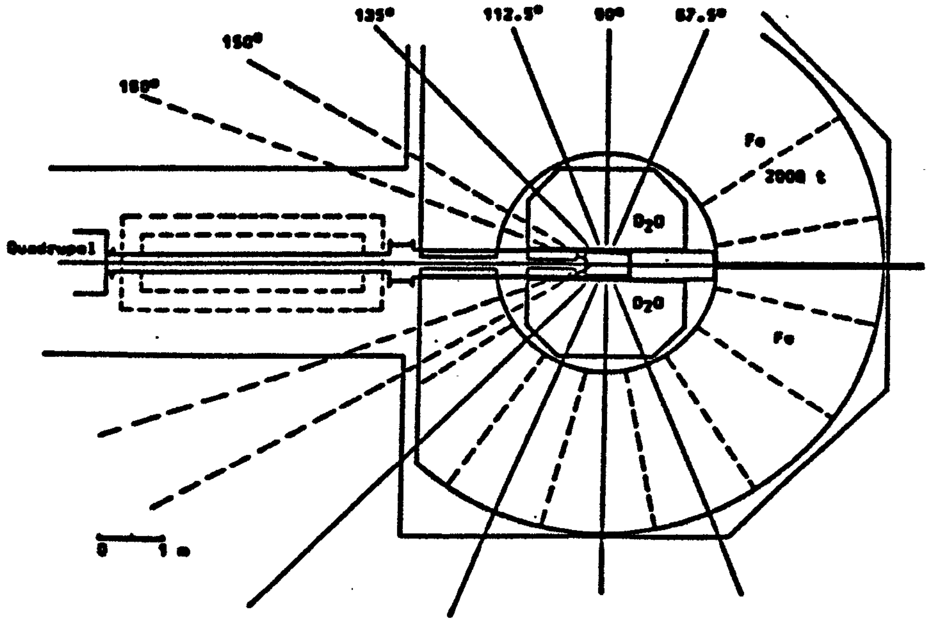


Fig. I-I.6. Schematic layout of the spallation neutron source.

J. An Intense Spallation Neutron Source for West Germany, J. E. Vetter, KFK Karlsruhe

1. Background

The first generation of research reactors, the neutron sources of today in West Germany, will soon reach an age where significant modifications will be needed to maintain safe and reliable operation. Because of this situation and an increasing demand for irradiation capacity, a modern powerful neutron source in West Germany has been discussed. In 1977 the "MFR Ad Hoc Committee" was appointed by the Minister of Science and Technology to discuss a neutron-source project, which at that time was conceived to be a medium-flux reactor (MFR). The MFR conceptual design, as proposed, is still a viable option and is regarded as an alternative to a spallation neutron source, which was recently recommended by the panel as the most promising concept.

This recommendation was preceded by a discussion with a subgroup which studied various machine concepts under the following assumptions:

- The source should deliver a time-average thermal neutron flux of 6×10^{14} n/cm^2·s, called 'basic machine' in the remainder of this discussion.
- The new source should present the option to increase the neutron flux to a substantially higher value.

It was concluded by the panel that these specifications can be met, but that the needs of the experiments and the capabilities of the machines should be better defined in a two-year study (100 man-years of effort) which would preceed a final decision on construction of such a facility.

2. Concept of the Basic Machine

It is assumed from current experience that a thermal neutron flux of 6 x 10^{14} n/cm^2·s can be produced by a 600-MeV, 10-mA proton beam. Taking this as the reference for the basic machine, the following target and accelerator configurations were discussed:

- a liquid Pb-Bi streaming target with various geometries
- a rotating water-cooled solid target
- a two-stage sector focusing ring cyclotron (RC) proposed by SIN, Villigen
- a pulsed linear accelerator (LA) designed by KFK, Karlsruhe.

The main parameters of the two machine designs are compared in Table I. Comparison of the accelerator schemes results in only little differences in:

- capital cost
- operation cost
- power consumption
- R & D and construction work.

Some essential differences can, however, be stated in:

- time structure of the beam
- capability of upgrading and flexibility for additional applications.

Cyclotrons are cw operating machines. When being pulsed, the average current decreases. The linac needs to be pulsed in any case for reasons of power economy. The duty cycle of 10% results in a peak current of 10 times the average current which offers the possibility to increase the peak neutron flux in a suitable target/moderator arrangement. In addition, the fast-neutron background can be suppressed by TOF differences.

3. Upgrading Options

Several options to upgrade the 'basic machine' have been discussed. These options are reviewed in Table II.

It should be pointed out that the option to increase the neutron flux is important as it justifies the higher cost and complexity of an accelerator-based source as compared to a reactor system. The comparisons shown in Table II demonstrate that the linear accelerator offers possibilities of either increasing the average flux or, by an additional storage ring, the peak flux. Basic machine and upgrading options will be studied in more detail in the next two years by the KFA and KFK laboratories within the ICANS.

TABLE I

ACCELERATOR CONCEPTS

	RC	LA
Injection energy (MeV)	8	0.5
Intermediate energy (MeV)	85	100
Final energy (MeV)	600	600
Frequency of operation (MHz)	60	100/300
Average beam current (mA)	10	10
Peak beam current (mA)	10	100
Duty cycle	CW	10%
Machine length (m)	-	500
Machine extr. radii (m)	3.2/5 7	-
Av. beam power (MW)	6	6
Av. rf cavity power (MW)	4.5	4.2
Mains ac power (MW)	21	21
Construction cap. cost (M$)	95	100
Annual operating cost (M$)	13	15

TABLE II

UPGRADING OPTIONS

Option	RC	LA
Higher average beam current	Not feasible, problems with beam instability and extraction	Increase of factor of 3 feasible with no modification to system but increase of power consumption from 21 to 56 MW
Higher peak beam current	Not possible	Depends on confidence in beam losses and development of peak power amplifiers
Higher beam energy	Feasible by additional cyclotron stage by ~ factor of 3 but hi-current extraction questionable; Capital cost high	Feasible by continuous increase of accelerator length; Capital cost high
Storage ring added to accelerator	Feasible but limited current capability	Feasible, time structure can be matched; H^+/H^- acceleration possible; ultimate current limit to be evaluated

K. Mode of Operation and Target Layout for ILSE, G. S. Bauer, KFA Jülich

An Intense Linac-driven Spallation-neutron source for Experimental purposes (ILSE) is being considered as an alternative to a new medium-flux reactor for beamhole research in West Germany. According to the preliminary concept for the linac to drive the source, a proton energy of 600 MeV, mean current of 10 mA with pulsed operation of 10% duty cycle at 150 Hz is foreseen.[1] Initially it was intended to operate the source with a large D_2O moderator tank in a continuous fashion very much like a steady-state reactor. It is, however, recognized that the pulsed operation of the linac can be taken advantage of to improve the experimental conditions if it is possible to provide sufficiently efficient "fast" moderators, that is, moderators which do not smear out the neutron pulses excessively. It seems likely, that a peak-to-average ratio of 6:1 can be obtained. This would open up the following possibilities:

- synchronization of TOF experiments to the source gives a gain factor of 6
- gating the detectors of all instruments such that they are insensitive at the moment of the proton pulse drastically reduces the background
- gating the detectors of triple-axis spectrometers and diffractometers such that they are only sensitive when the neutrons of the desired energy arrive eliminates higher order contamination and reduces the overall background.

Since it is not anticipated that decoupling or poisoning of the moderators would become necessary, a good target/moderator coupling should still be possible. In addition to the above, fast and reflected moderators would have the following advantages:

- short lifetime of neutrons makes them less sensitive to thermal neutron absorption in the target and hence gives greater flexibility in the choice of target material
- small size allows shielding to begin closer to the target, thus saving a large amount of iron at the outer circumference of the shield.

In order to avoid having a separate moderator for each beamhole, a horizontal target arrangement seems to be preferable, with moderators arranged above and below the target and each viewed by several beamholes.

In view of the high heat density (~ 10 MW/ℓ) which has to be dissipated in the target, a flowing Pb-Bi-eutectic as proposed for the Canadian ING project[2] and for the SIN target[3] seems to be a good choice, although a window, as in the SIN concept would probably not be feasible in our case. The advantages of a vertically streaming Pb-Bi/target, as shown in Fig. I-K.1, are:

- full access to the outer circumference of the shield
- continuous removal of certain hazardous species of active nuclei possible
- no mechanical stresses in target
- high potential for increasing target power.

The following disadvantages should be noted:

- no possibility of diluting target material to increase length of neutron source
- no flexibility in choice of target material
- vacuum/target interface allows evaporation of volatile species such as Hg or Po produced in the target
- choice of structural materials in target region limited by corrosion effects (Zr cannot be used without cladding)
- high temperature is likely to enhance swelling and He embrittlement of structural materials
- beamholes arranged in a tangential fashion with respect to the target cannot use common fast moderator
- proton-beam line above the target building and bending magnets add complexity to the whole system
- zero absolute pressure at target surface limits maximum flow velocity
- secondary Na-K cooling circuit is needed for heating the whole Pb-Bi; circuit also makes the system very complex.

Taking as a first stage a concept with a target of low-absorption cross section (Pb or Bi) and a LINAC of 600 MeV, 10 mA time average, 10% duty cycle at 150 Hz, the following options to improve the performance of the facility can be seen:

1) increase energy to increase peak flux
2) increase peak current in accelerator to increase peak flux
3) increase duty cycle to increase time-average flux
4) change target material to ^{238}U to increase neutron yield
5) add storage ring and reduce proton current such that it can be bunched and the source operates as a pulsed source
6) add storage ring, split off 10-15% of proton beam for bunching, and add second target station for pulsed source.

Option 1 through 3 entail increased operational cost, options 5 and 6 require mainly additional capital cost, with extra operational cost for option 6 and reduced operational cost for option 5. Option 4 seems to be the most economical one, but not feasible with a liquid-metal concept.

For these reasons an alternative target concept has been considered which avoids some of the difficulties of the liquid-metal target and gives the flexibility of choosing any of the above options.

The target material is arranged on the circumference of a 2.5 to 3.0-m diam wheel whose shaft is mounted vertically and consists of two concentric pipes bring the cooling water for the target down and back up the shaft (Fig. I-K.2). The beam hits the wheel at its outer circumference entering through the water-cooled window which is rotating with the target. In this way both the effective beam window and the target volume are about 200 times bigger than the "active" region at any given instant. A proton pulse of 100 mA and 700 µs duration will increase the target temperature in the target volume it hits by 25 °K at the hot spot. Between proton pulses, the target volume and the beam window are moved out of the beam region, which requires about 1.25 rev/s of the rotating target. If the target is initially subdivided into individual segments, it is possible to keep its maximum temperature below about 150 °C. Such an arrangement has the following advantages:

- low temperature pervents fatigue swelling, radiation swelling, and He-embrittlement both in the target and the beam window
- solid target provides first containment of spallation products
- target is completely inside shielding
- free choice of target material according to optimum flux production
- possibility of a heterogeneous target
- free choice of structural material for minimum neutron absorption
- horizontal proton beam allows use of fast moderators above and below the target
- changes needed for pulsed operation can be accomplished relatively easily
- in pulsed operation with ^{238}U target, the background from delayed neutrons and decay γ-radiation is considerably reduced.

Both a liquid metal and a rotating target concept will be evaluated in detail during the anticipated study period for the ILSE.

References

1. J. E. Vetter, this meeting.

2. G. A. Bartholomew and P. R. Tunnicliffe, "The AECL Study for an Intense Neutron-Generator," AECL-2600 (July 1966).

3. W. E. Fischer, this meeting.

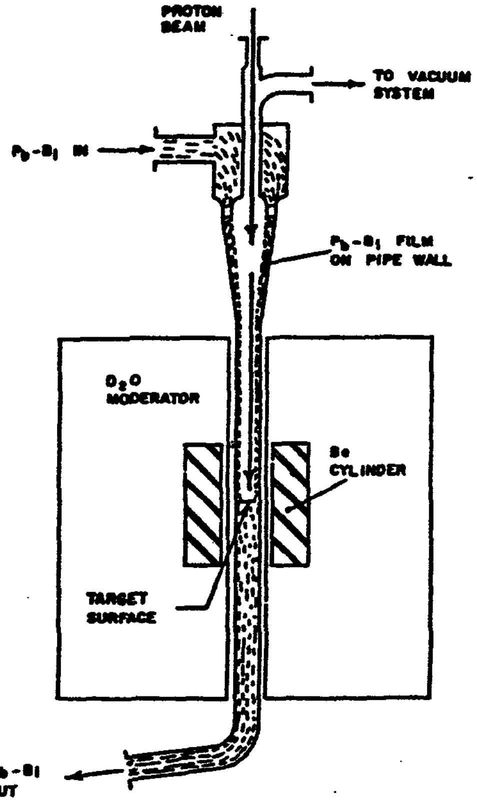


Fig. I-K.1. Schematic layout of liquid metal target system with vaned head as proposed for the ING-project. Power in target is expected as 4.5 MW. Some characteristic parameters are: Velocity v = 1 m/s, pressure drop ΔP = 4.3 bar, temperature rise ΔT = 125 °K.

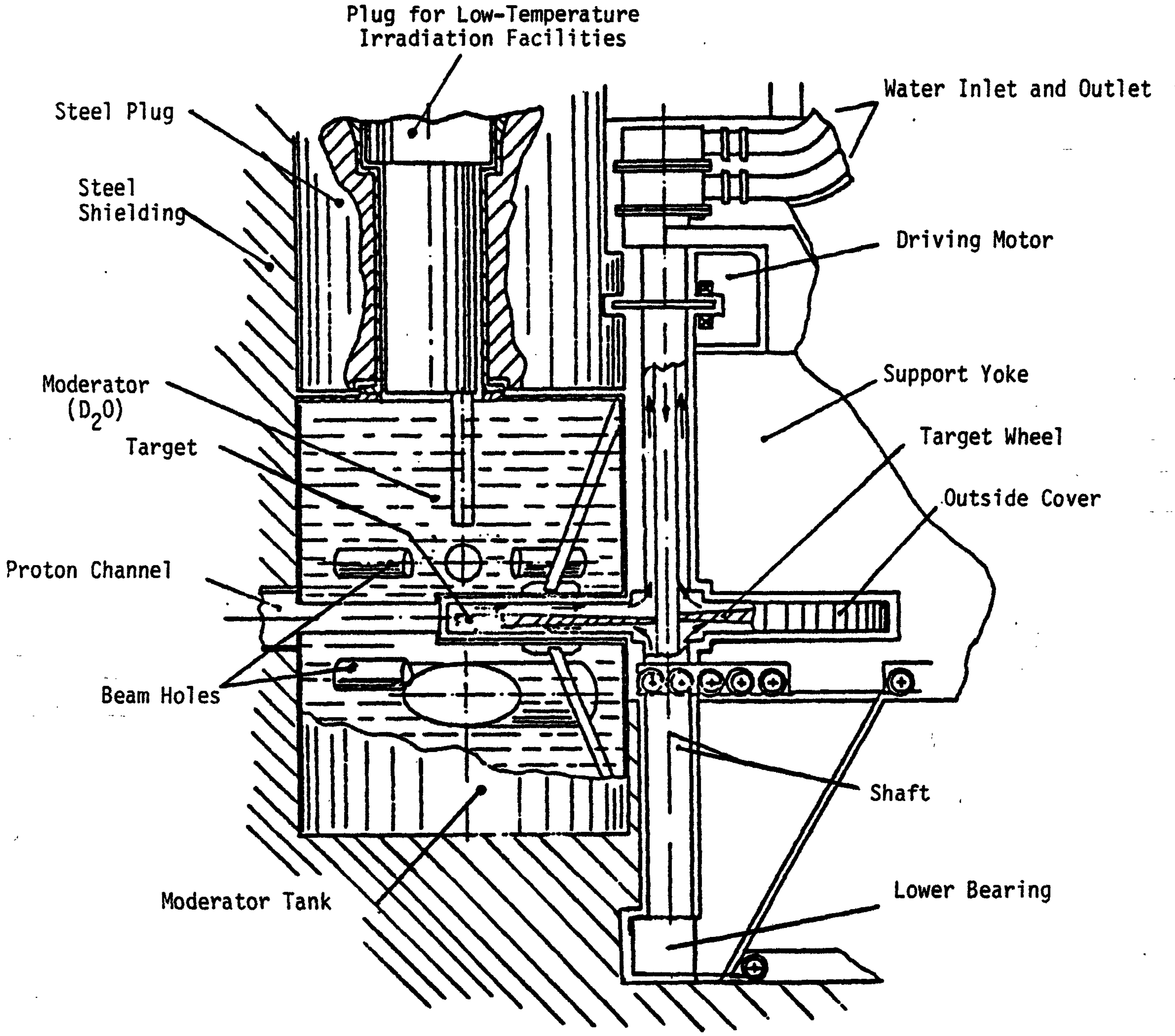


Fig. I-K.2. Schematic of target station with rotating target and big D_2O-moderator tank.

L. Some Recent Results and New Instruments at ZING P', J. M. Carpenter, ANL

Since its startup in late 1977, the performance of ZING P' has increased to its present level of about 8 x 10^{11} p/pulse, 8 n/p (estimated for the W target), and 10 Hz average repetition frequency. The Rapid Cycling Synchrotron (RCS) is operating from a stable oscillator and delivers pulses of ~ 100 ns duration. The target/moderator arrangement is shown in Fig. I-L.1. Two vertical beams are produced by two moderators, and three horizontal beams are produced by one moderator. A boron-containing vane above the moderator of beam V-2 prevents "cross-talk" with the horizontal-beam moderator. Instruments now operating are the Crystal Analyzer Spectrometer, the High Resolution Powder Diffractometer, and the Single Crystal Diffractometer. In place, but not yet operating, are the Chopper Spectrometer and the Ultracold Neutron Generator.

The Crystal Analyzer Spectrometer in beam V-2, is designed for chemical spectroscopy and is shown schematically in Fig. I-L.2. The distance from the source to the sample is ~ 4.0 m. Recent data on the scattering at 90° to 0.003 eV from ZrH_2 are shown in Fig. I-L.3 which gives the observed counts/channel vs time-of-flight. The elastic peak appears at channel 690. Elastically-scattered neutrons not removed by the Be filter (at room temperature in these measurements) and reflected by the pyrolytic graphite monochromator in second and third order appear at channels 320 and 220, respectively. Optic mode transitions in ZrH_2 are seen at channels 190 (138 meV, 1-2 transition), 162 (274 meV, 1-3 transition), and 152 (417 meV 1-4 transition). The instrument scientist is R. Kent Crawford.

The High Resolution Powder Diffractometer is now performing research measurements, and is shown schematically in Fig. I.L-4. The source-to-detector distance is ~ 20 m. The instrument is located in beam H-3. Calibration and profile parameters have been derived from scattering patterns of iron and silicon powders, which indicate $\Delta d/d \lesssim 0.3\%$ in the 160° detectors and $\Delta d/d \lesssim 0.5\%$ in the 90° detectors (constant with d). Data for Si are shown in Fig. I-L.5. Through the data points is the profile curve fitted to the reflections at positions indicated below the data. The residual of the fit shown below indicates the accuracy of the fit. A sample of $A\ell_2O_3$ (about 2 cm^3, two of the international standard samples used in diffractometer comparisons) was run for a period of about five days, and provided the patterns shown in Fig. I-L.6. The profile refinement extends from d = 0.5 Å to d = 2.18 Å, and produced parameters in good agreement with data derived from other high resolution diffractometers. The instrument scientist is J. D. Jorgensen.

The Single Crystal Diffractometer operated for the first time on March 15, 1979. Figure I-L.7 shows the instrument schematically. The distance from the source to the sample is 8.5 m, in beam H-2. The chopper is not yet a part of the system. The 20 x 20 cm^2 multiwire gas proportional counter (built cooperatively by ORNL and ANL personnel) provides data to a remote computer which stores data as function of position (x,y) and time (wavelength). The computer remotely operates the twelve-inch Huber gonimeter and the detector positioning drive. A 5-mm-diam by 9-mm-high NaCℓ crystal was placed in the sample position. Intensity data (points above eight counts per element) are shown on an x-y map in Fig. I-L.8, for wavelengths between $1.11 \leq \lambda \leq 1.33$ Å, showing the 440 reflection. The same data are plotted as intensity per element vs position in Fig. I-L.9. The distribution of intensity roughly reproduces the image of the crystal, broadened by the detector resolution and by parallax. Figure I-L.10 shows data (counts > 10 per element, $0.5 < \lambda > 3.57$ Å) accumulated in 1 1/2 h, with the crystal oriented to place reflections in the center of the detector; the 200, 331, 331 families are shown. To our knowledge, this is the first demonstration of a pulsed source time-of-flight Laue camera. The instrument scientists are S. W. Peterson and A. H. Reis, Jr.

The Chopper Spectrometer is shown schematically in Fig. I-L.11. Seven groups of 7 He^3 detectors span scattering angles $2° < \theta < 90°$. The distance from the source to the chopper is 10 m. The instrument is located in beam H-1. The spectrometer will enable spectroscopy with incident energies up to 0.5 eV. The instrument has not yet operated, but will begin operation in May 1979, driven from the same oscillator that drives the accelerator. The instrument scientist is C. A. Pelizzari.

The Ultracold Neutron Generator is being installed for operation in May 1979. This is the first stage of a series of measurements leading to a measurement of the neutron electric dipole moment. The current goal is to produce ultracold neutrons ($v \lesssim 7$ m/s) and store them in a totally reflecting bottle. The experiment is shown in Fig. I-L.12. Neutrons from the source stream upward in beam V-1, to strike a mica crystal array ($d \sim 20$ Å), moving at 200 m/s and phased so as to be in reflecting position at the time of arrival of 400 m/s neutrons. Neutrons are backscattered from the crystal to nearly zero velocity. The principle is illustrated in Fig. I-L.13 which shows the volume around 400 m/s in velocity space which is reflected by the crystal. After reflection, this volume, containing approximately the same phase space density of neutrons, is shifted to the origin ($v \approx 0$). A portion of this shifted volume is accepted by the bottle, which is connected through an intermittently-opening rotating valve, to the region of the source. The experiment will operate from the same stable oscillator as drives the accelerator. The leader of the experiment team, which involves personnel of three universities and three divisions of ANL, is T. W. Dombeck, Department of Physics and Astronomy, University of Maryland.

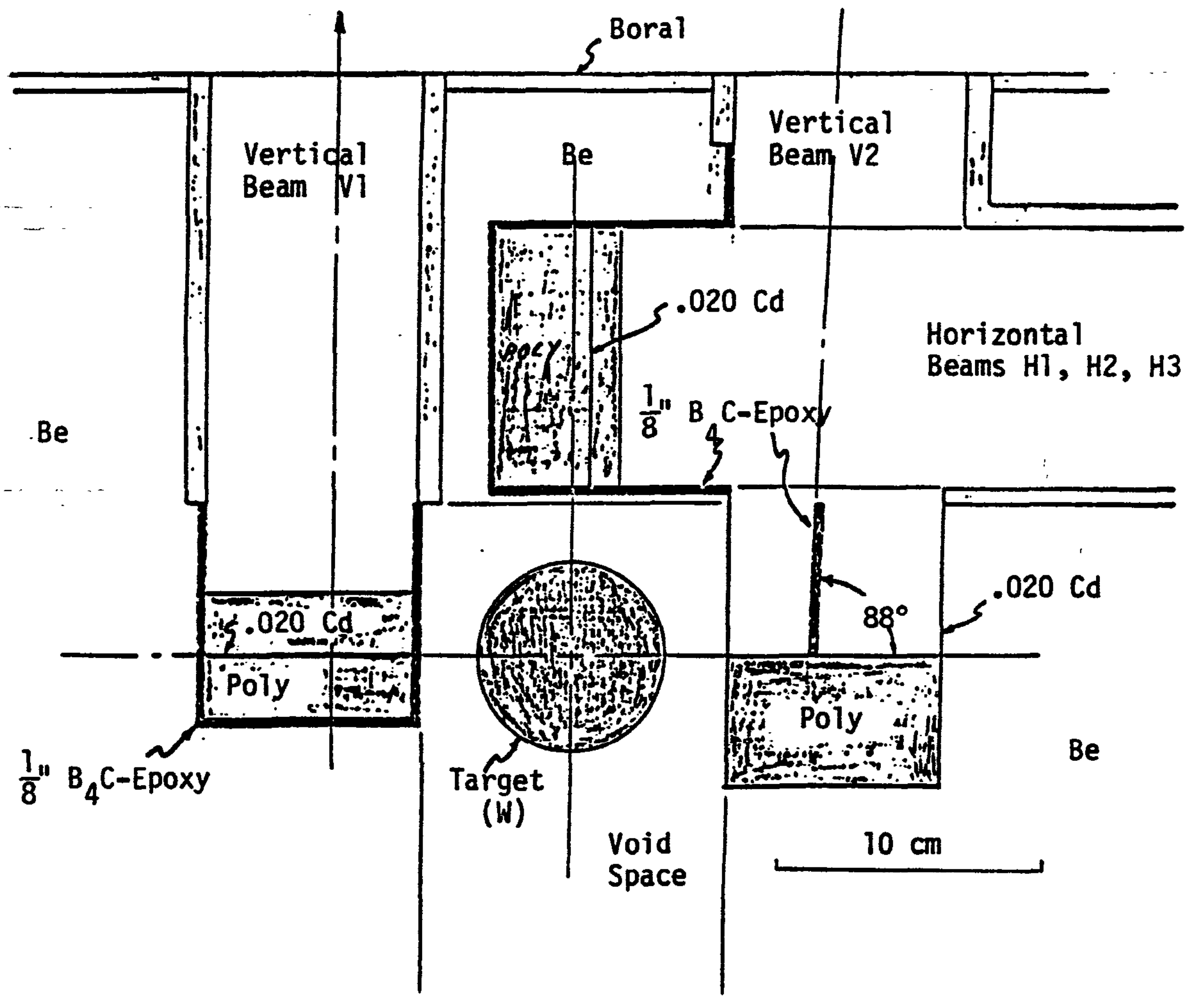


Fig. I-L.1. ZING-P' target/moderator arrangement.

ZING - P'

CRYSTAL ANALYZER SPECTROMETER

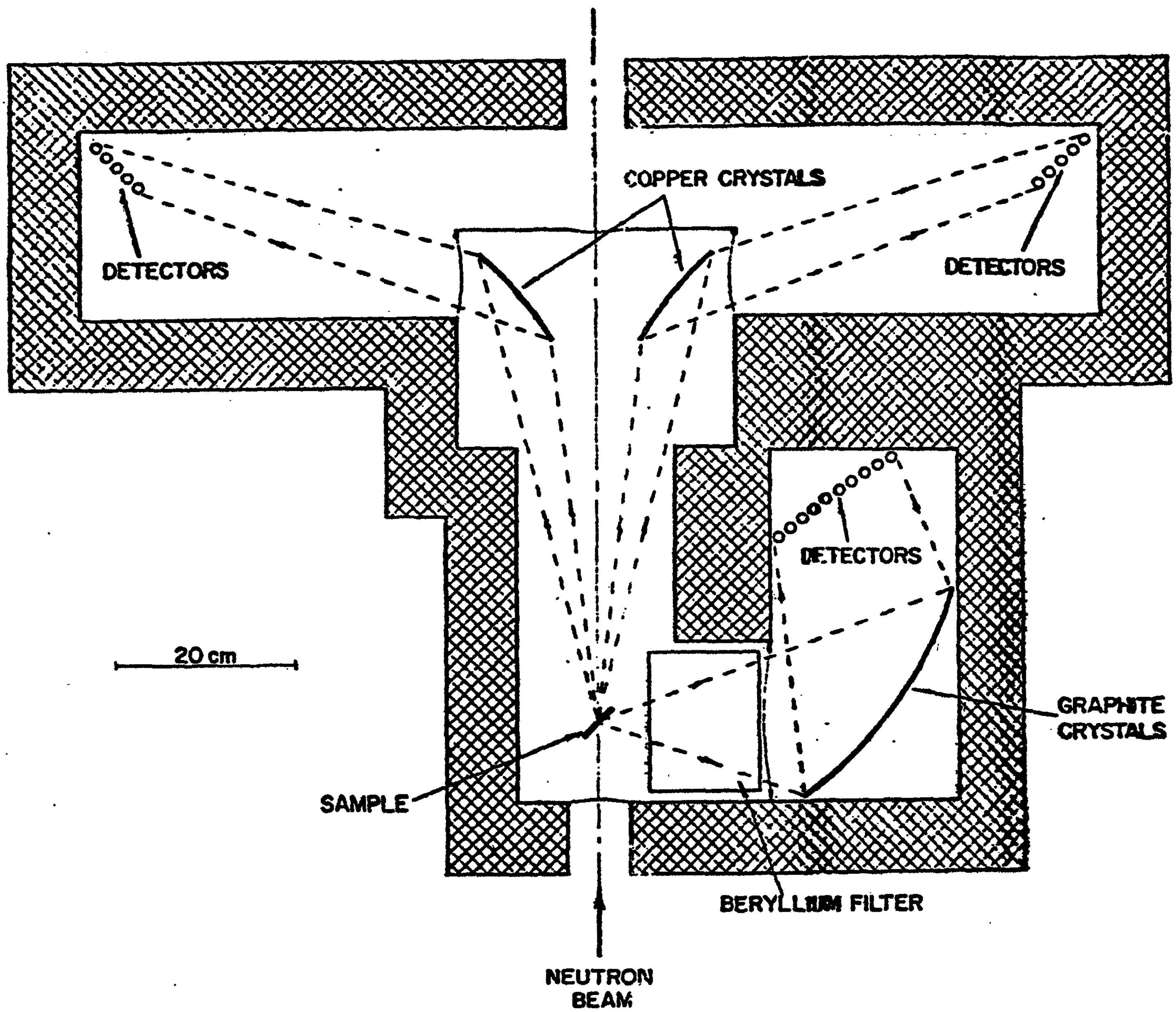


Fig. I-L.2. Crystal analyzer spectrometer.

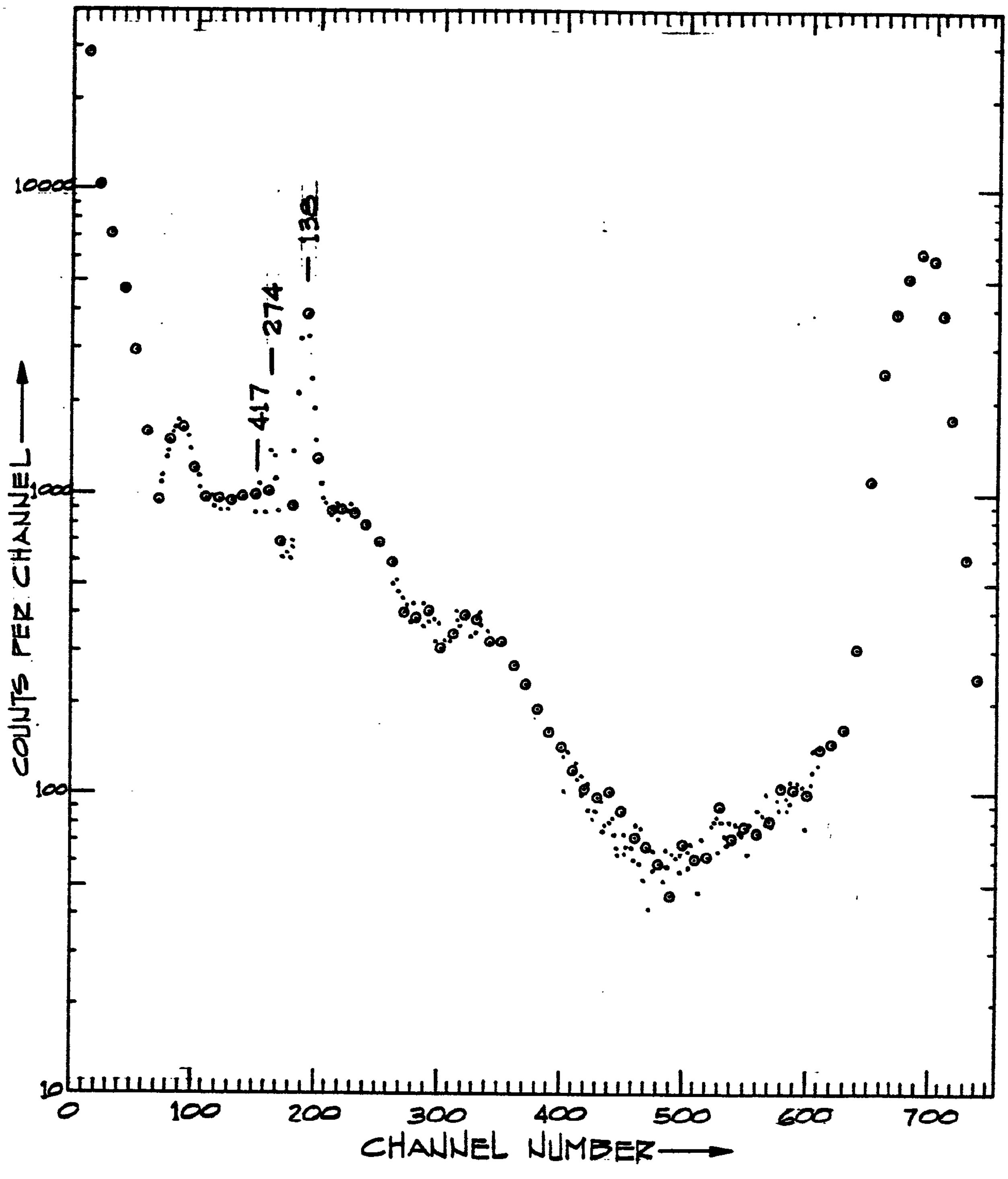


Fig. I-L.3. Neutron scattering at 90° from ZrH_2 using crystal analyzer spectrometer.

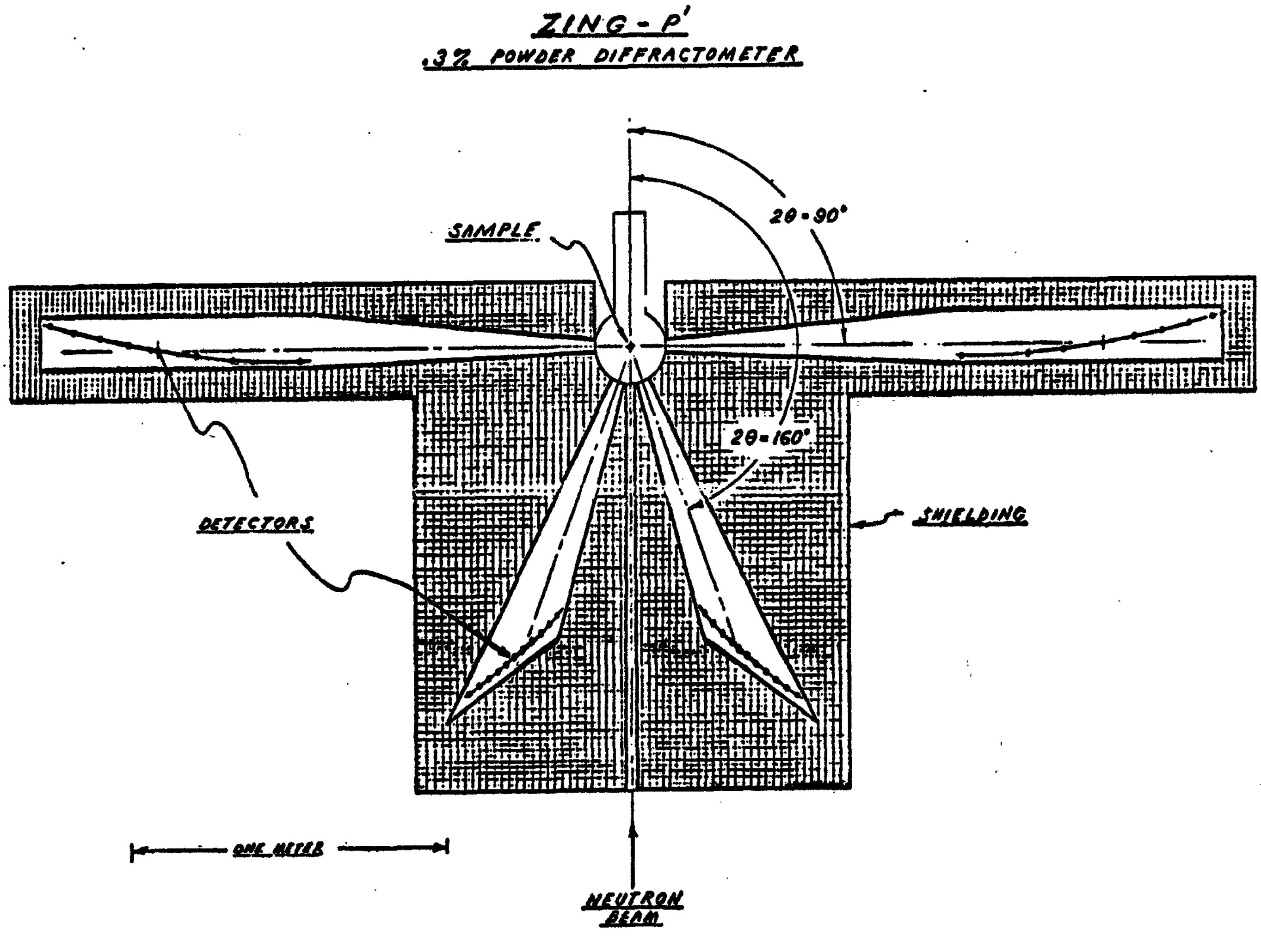


Fig. I-L.4. High resolution powder diffractometer.

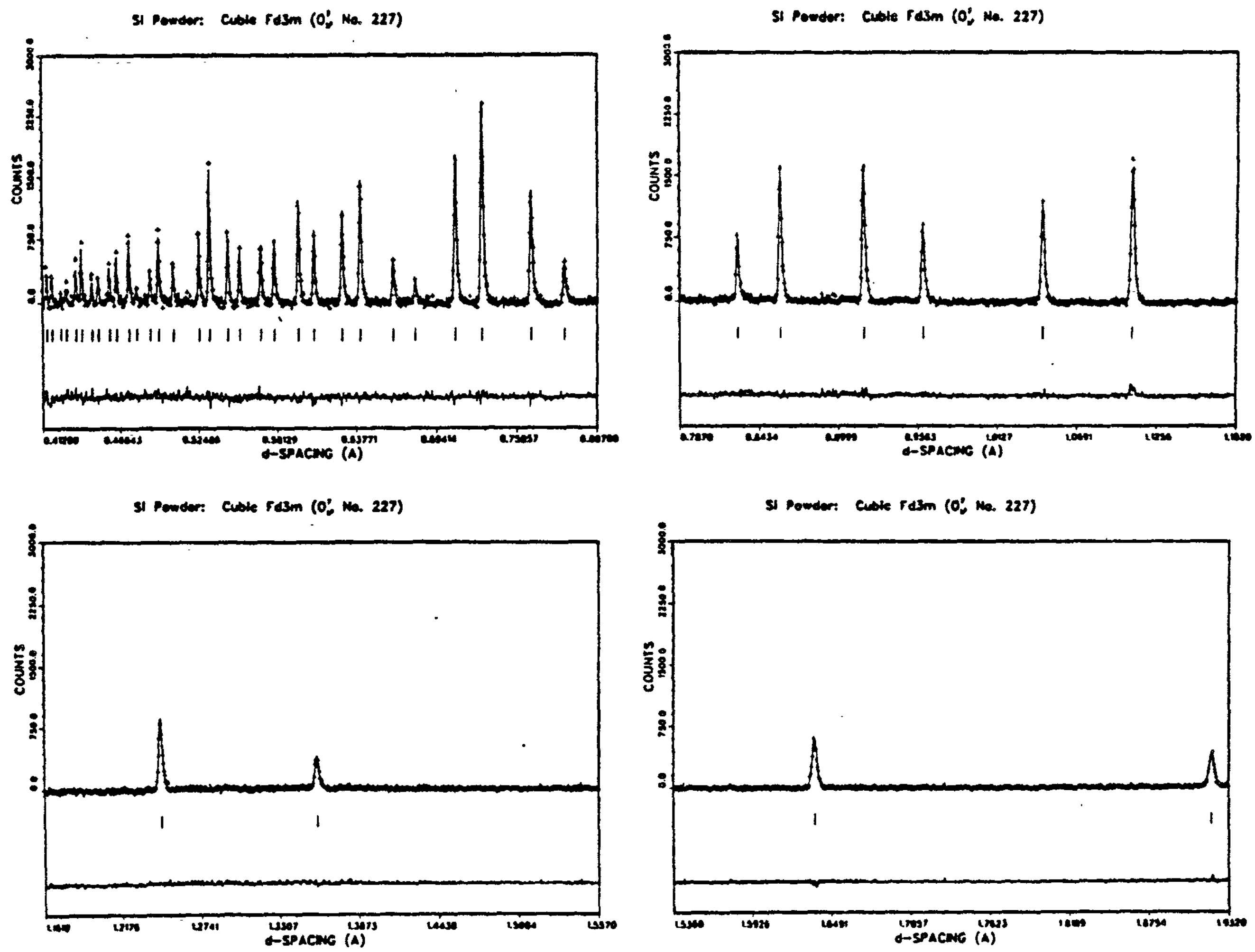


Fig. I-L.5. Data for Si using high resolution powder diffractometer.

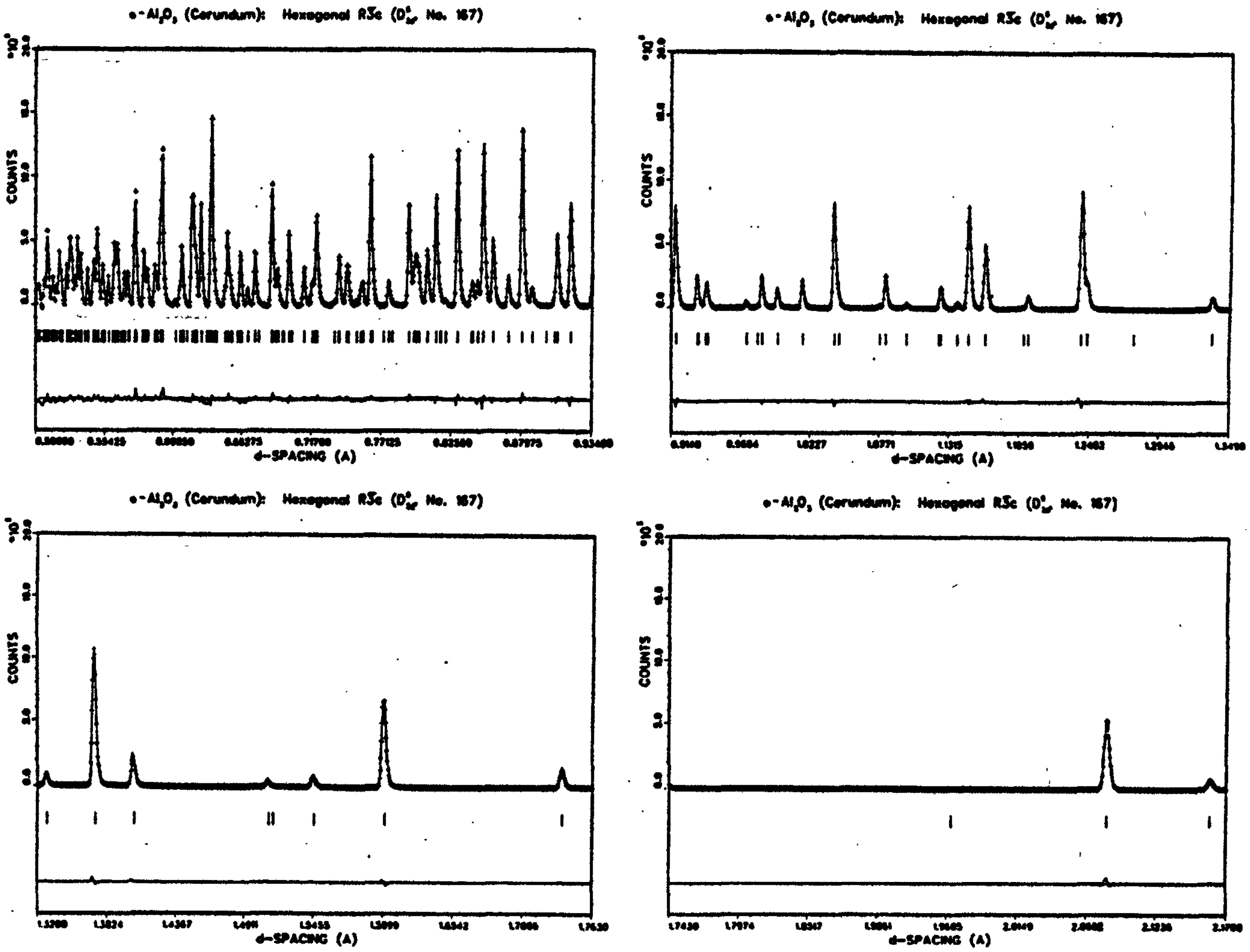


Fig. I-L.6. Data for $A\ell_2O_3$ using high resolution powder diffractometer.

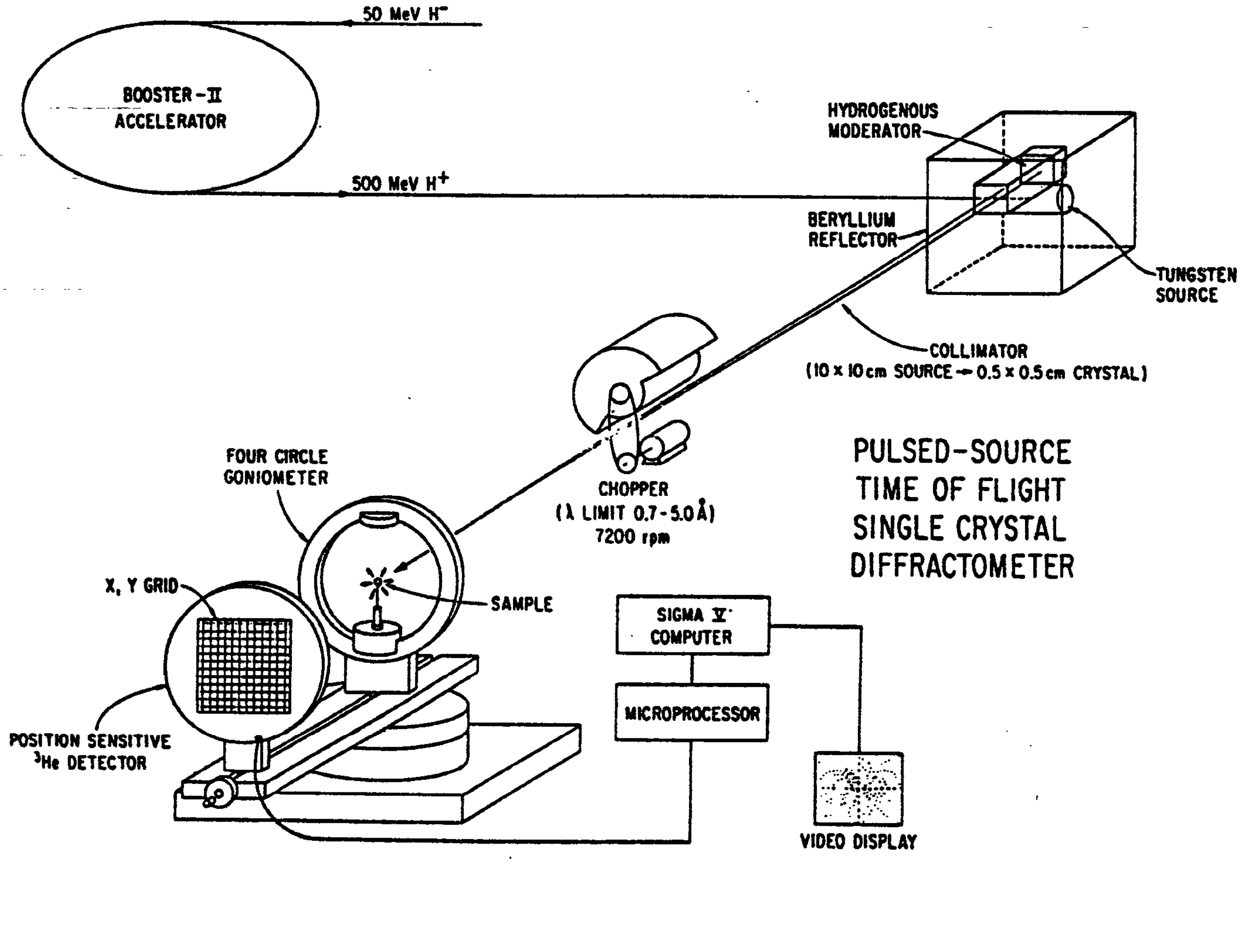


Fig. I-L.7. Single crystal diffractometer.

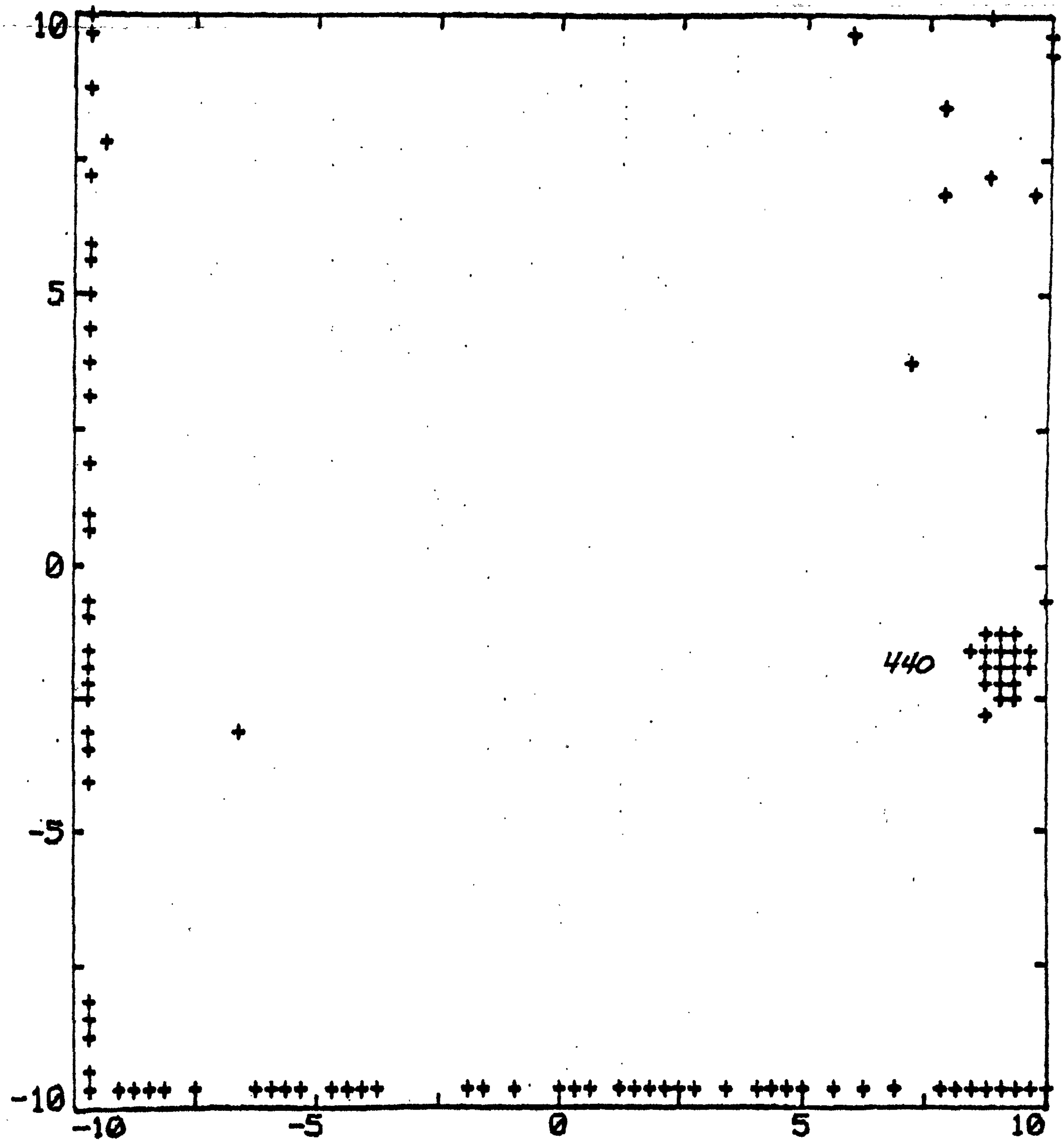


Fig. I-L.8. Intensity data on x-y map for 20 x 20 cm^2 multiwire gas proportional counter.

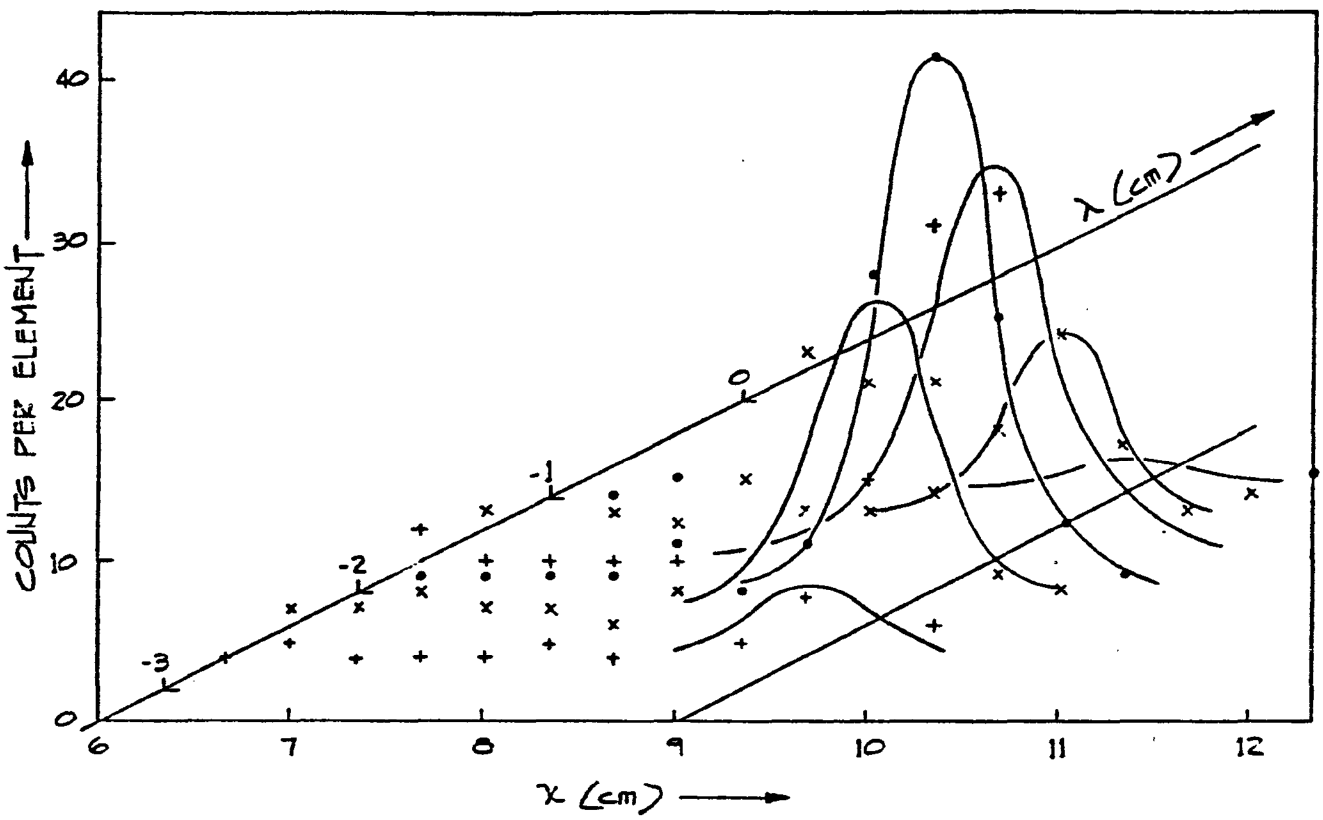


Fig. I-L.9. Intensity per element vs position for 20 x 20 cm^2 multiwire gas proportional counter.

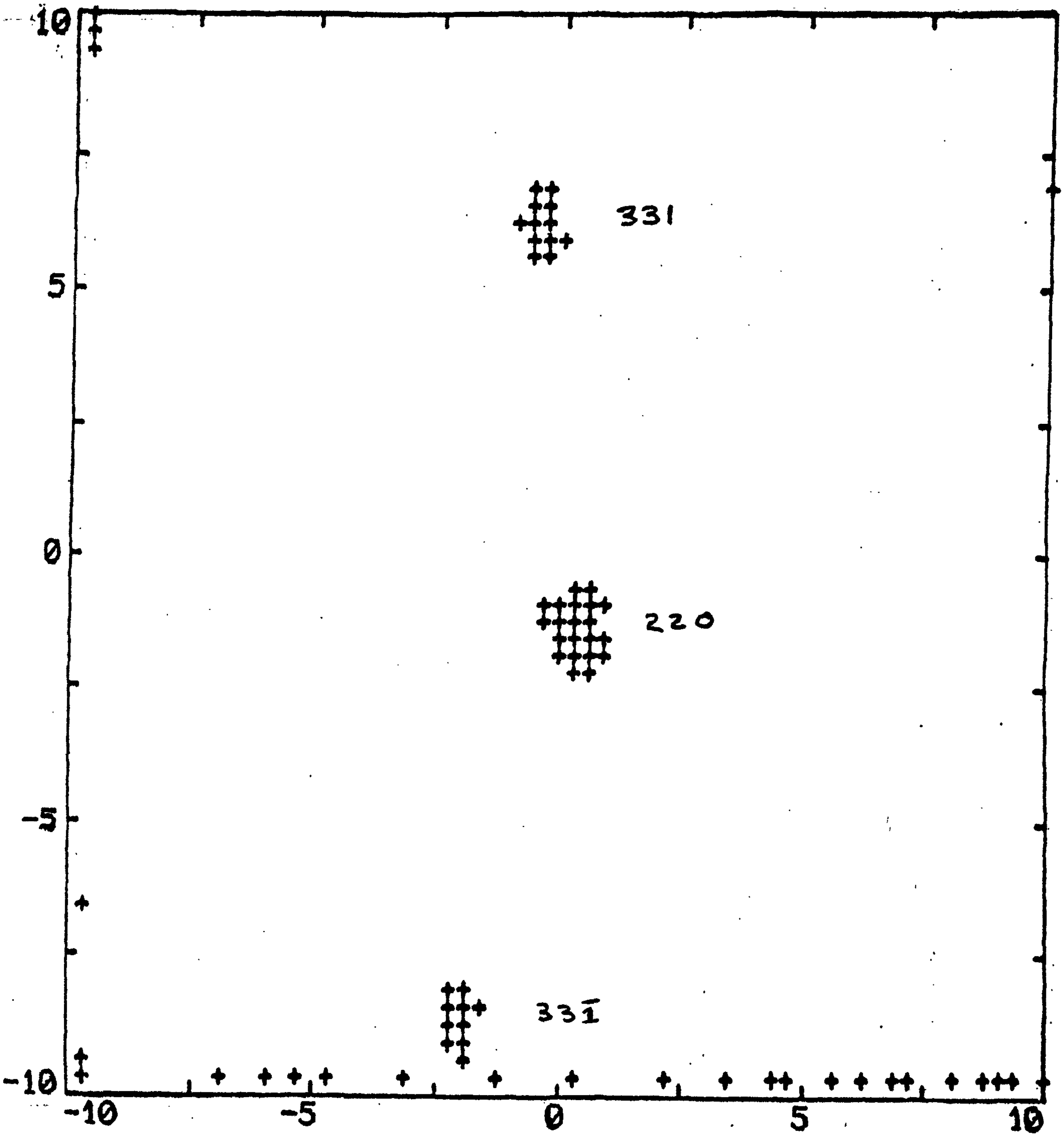


Fig. I-L.10. Illustration of a pulsed source time-of-flight Laue camera.

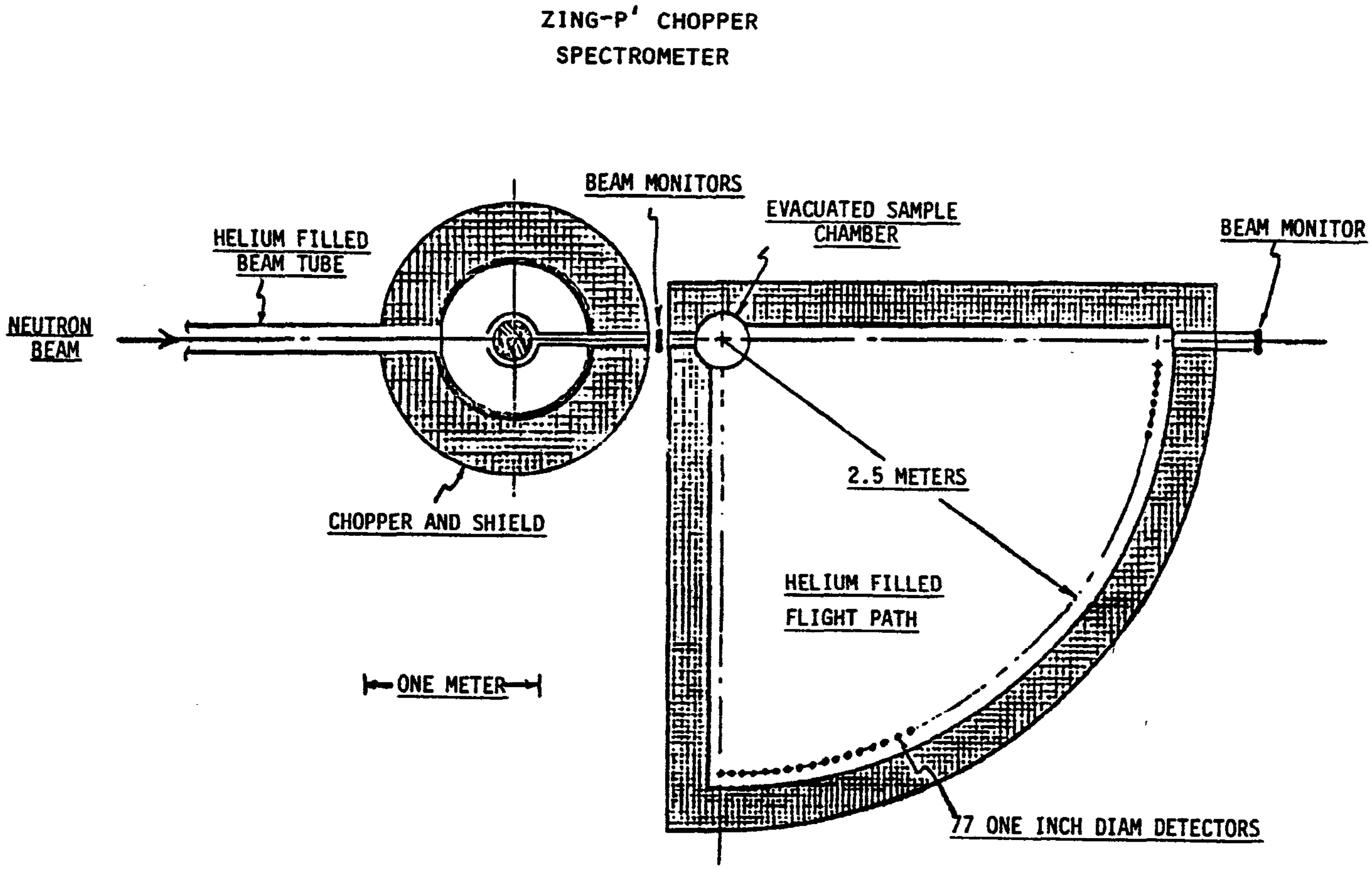


Fig. I-L.11. Chopper spectrometer.

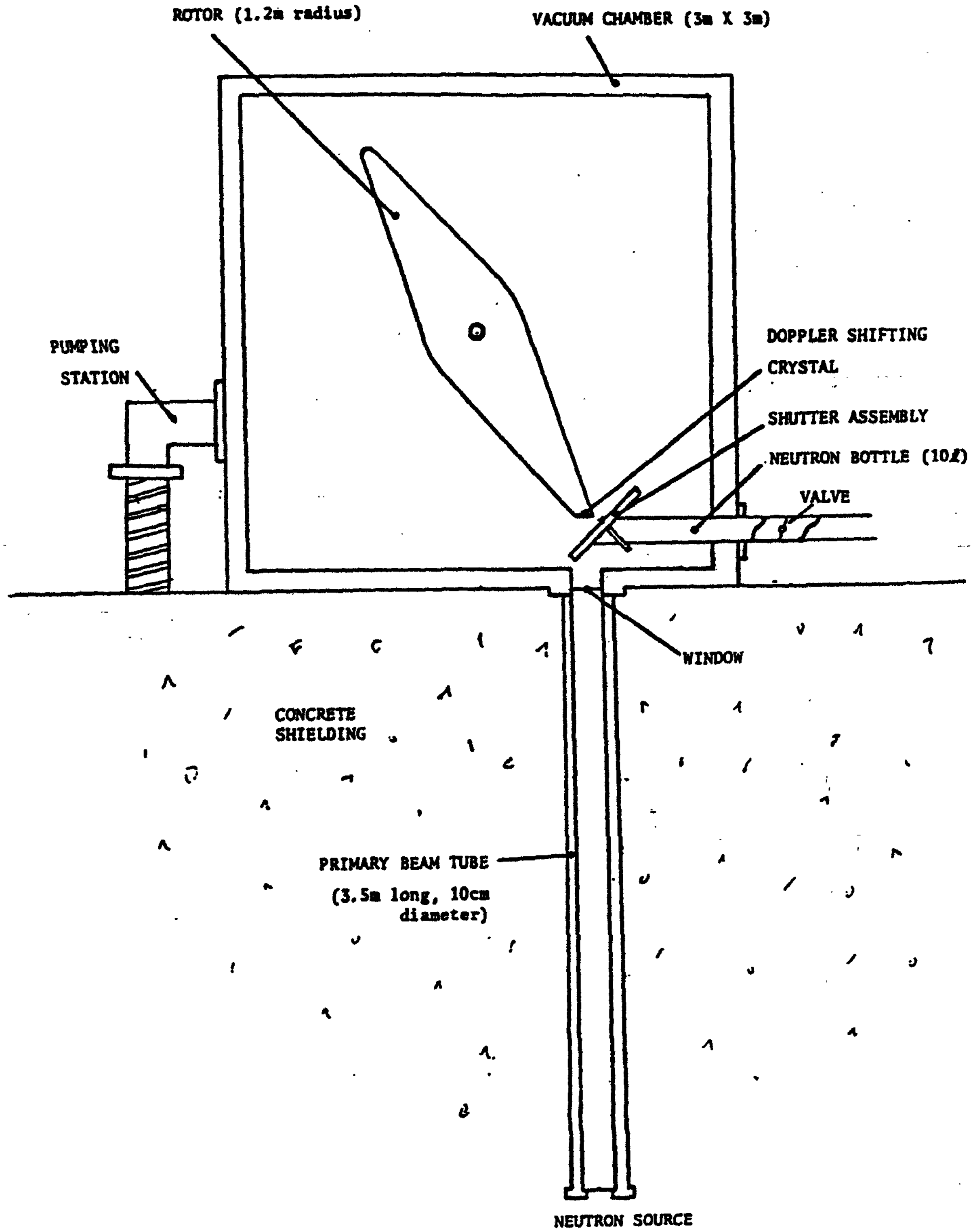


Fig. I-L.12. Ultracold neutron generator.

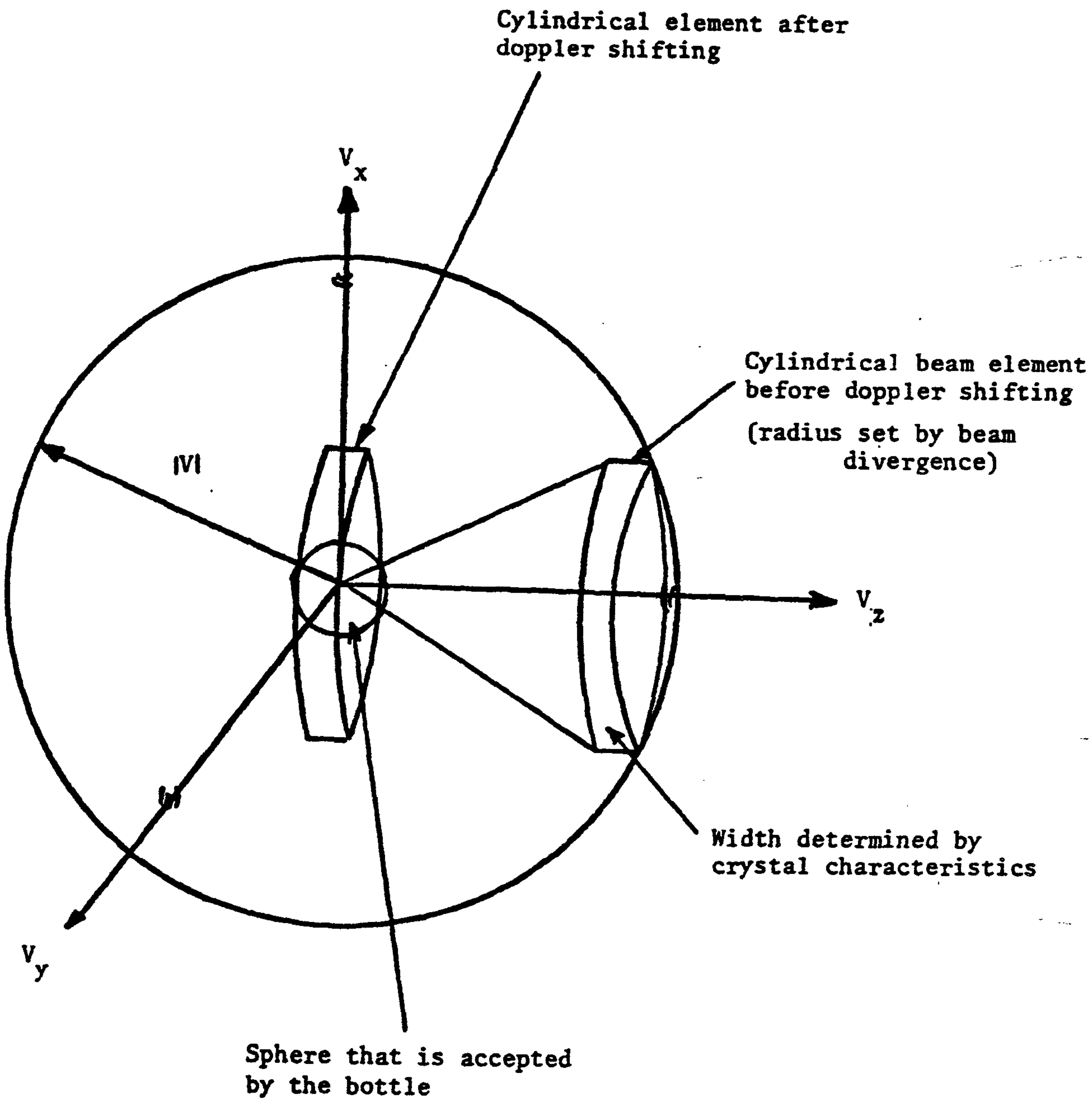


Fig. I-L.13. Principle of ultracold neutron generator.

II. GENERAL SESSIONS - TARGET STATIONS

The following topics were used as guidelines for discussions during the general sessions on target stations:

Neutronics

- target/moderator design criteria
- target materials
- moderator materials
- reflected/decoupled and bare moderators
- cold moderators
- experimental-data/code-verification
- moderator heating
- backgrounds in neutron beams

Engineering

- engineering aspects of neutronic considerations
- target station diagnostics
- versatility inside target cavity interface between proton beam line and target station
- proton beam dumps
- shielding
- beam ports and shutters
- radiation monitoring

The sessions were unstructured. Summaries of most of the discussions held during the general sessions on target stations follow.

A. Target Development Work at the Rutherford Laboratory, A. Carne, RL

1. Uranium Growth Studies

The Rutherford Laboratory has a development contract with its neighbor establishment, AERE Harwell, to provide a metallurgical understanding of the behavior of Zircalory-2 clad uranium target plates during fabrication and operation under the SNS proton beam, and to determine possible methods of failure. There is further collaboration with Harwell in the design of a target for their 136-MeV electron linac. A test electron linac with an energy of about 15 MeV has been available to make studies of the effects of thermal cycling as a function of center temperature, uranium thickness (the cladding being 0.25 mm and constant), and plate fabrication by the hot rolling (HR) or hot pressing (HP) process. Preliminary results (due to M. S. Coates of AERE) are shown in Table I. The plates were air-plast cooled. Temperature change/pulse was ~ 30 °C. The centerline temperature was measured by thermocouples embedded in the uranium. The results indicate a possible threshold below which thermal cycling growth may be small as suggested by Gittus, "Metallurgy of Uranium". Also the test result, taken to determine the gross effects of beam switching on and off, indicate that the pulse-to-pulse thermal cycling is a more important effect than gross temperature changes.

2. Code Development

Development of target codes has continued, under F. Atchison. The RL version of the HETC package now contains the following major modifications:

- inclusion of high-energy fission as a competing process
- modified treatment of low-energy neutron induced fission
- use of ENDF/B cross-section data in O5R
- corrected Coulomb scattering code which allows segmentation of the target into plates.

For an input 800-MeV proton beam of 3×10^{13} p/pulse, 50 Hz, with a "square parabolic" distribution

$$\frac{I}{I_0} = \left[1 - \left(\frac{x}{x_0}\right)^2\right]\left[1 - \left(\frac{y}{y_0}\right)^2\right]$$

and $x_0 = y_0 = 3.816$ cm, incident on a solid uranium ($10 \times 10 \times 30$ cm^3) target, the following preliminary results have been obtained:

- total energy deposition 350 kW
- peak energy deposition 0.94 kW/cm^3
- peak-to-mean ratio in the target 8:1 when the entire target is included, 5:1 when only the volume under the beam is included.

Axial variation of the energy deposition indicates the peak at 2.5 cm, followed by an exponential decay with an effective mean-free path of 9.2 cm. The number of uranium nuclei destroyed per incident 800-MeV proton was found to be 4.9 fissions, 1.8 spallations, and 2.6 (n,γ) captures, totaling 9.3 nuclei-destroyed proton.. The saturation activity has been based on 3 short lived products/fission, 2 per (n,γ) and 1 per spallation giving a total of $\sim 1.5 \times 10^6$ Ci. The corresponding decay heating is 26 kW; this latter figure has been included in the above total energy deposition.

3. Target-Plate Thickness

The above data has been used to define a preliminary set of target plate thicknesses. The optimum transverse dimensions of a clad-plate target are now being estimated, using as a figure-of-merit the 1 eV normal neutron flux from the 10 x 10 cm^2 open face of an H_2O moderator above a practical Inconel target box, with the target/moderator immersed in a 70-cm cube of D_2O reflector. The target plate thicknesses have been chosen to keep the centerline temperature in the uranium < 400 °C. The following preliminary set of plates has been obtained: 12 at 0.65 cm, 4 at 0.85 cm, 4 at 0.95 cm, 4 at 1.25 cm, 2 at 1.75 cm, and 5 at 2.45 cm; total 31 plates with an average uranium density of 84%.

The temperature has been held at 400 °C to keep clear of the regime of cavitation swelling, which appears to peak at 425-450 °C. Also at this temperature, and below, the effects of thermal cycling are expected to the reduced. Other radiation growth effects will be reduced by metallurgical processing.

4. Spallation Product Gases

Production of fission/spallation product gases has been estimated, with the following values at NTP:

H_2	He	Xe	Kr
1.6ℓ	0.35ℓ	1.46ℓ	0.29ℓ

with a total 3.7 ℓ/yr. If, as expected, hydrogen dissolves or diffuses through the material, this value reduces to 2.1 ℓ/yr. These gas quantities are not expected to cause problems.

5. Burn-up Rate

The term "burn-up" rate is given above as 9.3 ^{238}U nuclei destroyed per proton, of which 4.9 are due to fission. The corresponding rate for the peak plate is 2.1%/yr, with about 1.1%/yr due to fission. Comparing with conventional reactor fuel elements, a target lifetime in excess of four months can be expected.

TABLE I

GROWTH STUDIES FOR URANIUM PLATES

Nominal U thickness	Fabrication	Temp (°C)	No. of Cycles	Total Growth	Growth /mm for 10^6 cycles
1 mm	HR	350	10^6	nil	nil
1 mm (same plate)	HR	500	10^6	5	5 ± 1
(repeat same)	HR	500	10^6	5	5
2 mm	HP	500	10^6	17	8.5
2 mm	HP	500-250	10^6 (0.25×10^6)	4	—

B. SNS Target Station and Shutters, A. Carne, RL

1. Target Station

The SNS target station has been designed to reduce the radiation at the outside surface of the bulk shield to less than 0.75 mrem/h. The shielding will, however, be weakened by the proposed 18 neutron-beam tubes serving the instruments in the experimental areas. The bulk shield will be a massive structure of mainly iron and concrete; nevertheless the proposed conceptual design has the flexibility to meet future experimental requirements which may call for changes in beam-tube layout within the bulk shield. Within the bulk shield each beam tube will be terminated by a shutter.

The bulk-shield dimensions have allowed for the angular distribution of fast neutrons emerging from the target. For a solid ($10 \times 10 \times 30$ cm^3) uranium target the following shielding thicknesses have been obtained:

to beam direction	0°	3.2-m Fe + 1.5-m concrete,	total 4.7 m
	90°	2.7-m Fe P 1.0-m concrete,	total 3.7 m

To these dimensions are added 0.4-m Fe (1 TVL) to anticipate possible future trends in permissible dose rate.

The target assembly is contained within a "void vessel" of 1.5-m radius, this dimension being set by the requirement to have 18 neutron beam ports each of about 20-cm width. The atmosphere within the void will be helium, at reduced pressure.

The overall radius of the target station at the nominal 90° direction will then be 1.5 m + 3.7 m + 0.4 m = 5.6 m. However, for instrument design purposes, this radius will be taken to be 6.5 m to allow the addition of loose shielding and services. A rough plan of the target station is shown in Fig. II-B.1. At the outer region of the bulk shield (radius 3.5 m to 5.6 m) the neutron beam tubes will be contained within inserts into the shield, in a pill-box fashion as shown in Figs. II-B.2 and II-B.3. These inserts will be fabricated off-site and will enable accurate construction and alignment into the shield. The nominal angle between beam tubes is 18°, however the insert system will allow any beam tube to be moved to view any moderator within the target assembly.

2. Beam Shutters

In the inner region of the bulk shield (radius 1.5 m to 3.5 m) will be a system of vertically operated shutters. Each shutter will be 2-m deep by 0.4-m wide (75% Fe and 25% concrete) and will lie along radii with the target at center. With a shutter closed the radiation dose rate in the beam tube at 10 m from a wing moderator will be reduced from ~ 10^4 rem/h to 2.5 mrem/h. The nominal aperture in the shutter is 20 x 20 cm^2 which will allow the flexibility mentioned above.

Collimators inserted within this aperture will be determined by instrument requirements.

The height of each shutter is nominally 4.5 m, in 3 sections the center one of which carries the beam aperture. The total weight of each shutter is about 20 tons. The large height of the shutters places the shielding voids at the top and bottom well away from the radiation source to reduce the shield weakening. The shutters will be operated hydraulically, or perhaps by simple mechanical means from the top of the target station and alignment tolerance of ± 0.1 mm can be easily met.

The shutters are basically plain rectangular boxes, guided by roller systems. They are thus not expected to lead to jamming problems (for example, against the shielding wedges between each shutter). If a shutter needs to be removed (possibly to replace a collimator) it can be removed piece by piece vertically. Thus no disturbance is caused to the experimental set up on the floor of the hall.

In operation, the shutters are fail-safe, the vertical fall required to completely close off a beam being less than 15 cm. If a shutter is closed for any reason the other beam tubes are unaffected.

The shutter systems are contained in annular shaped vessels (see Fig. II-B.3), and the atmosphere is again helium (but at slightly greater pressure than the void vessel). Thus, two windows are required. Neutron beam loss due to these windows and the helium gas is less than 2.5%. Access to the windows is possible through the shielding insert. To reach the inner window the shutter will be lifted above the window height. Remotely operating jigs are being designed to do this function.

The shutters will be cooled by circulating the helium gas in the vessels. Installation of the target station is scheduled to begin in September-October 1979.

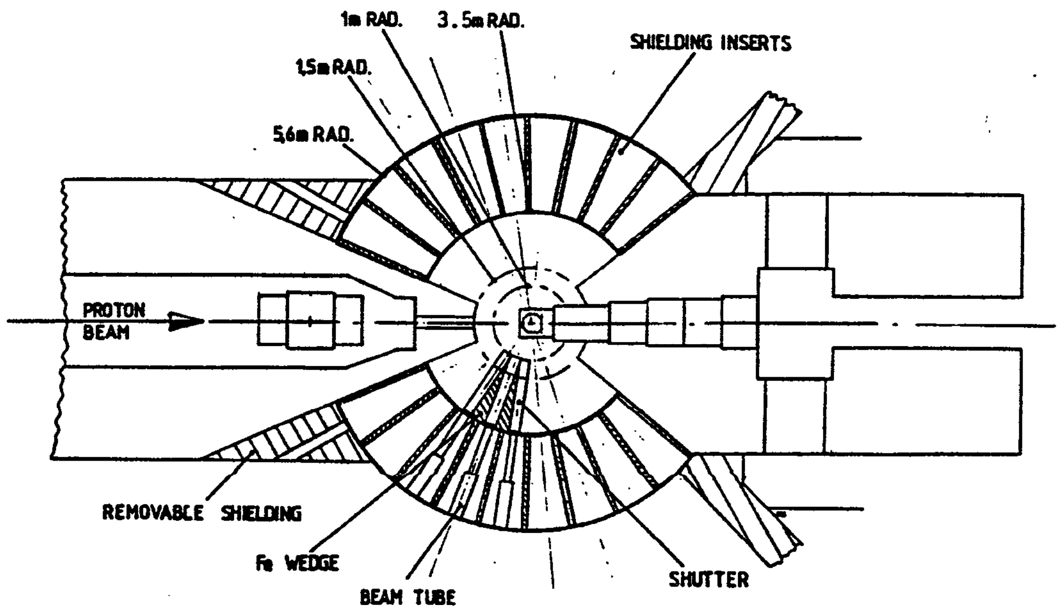


Fig. II-B.1. Target station layout showing shielding insert and shutter system.

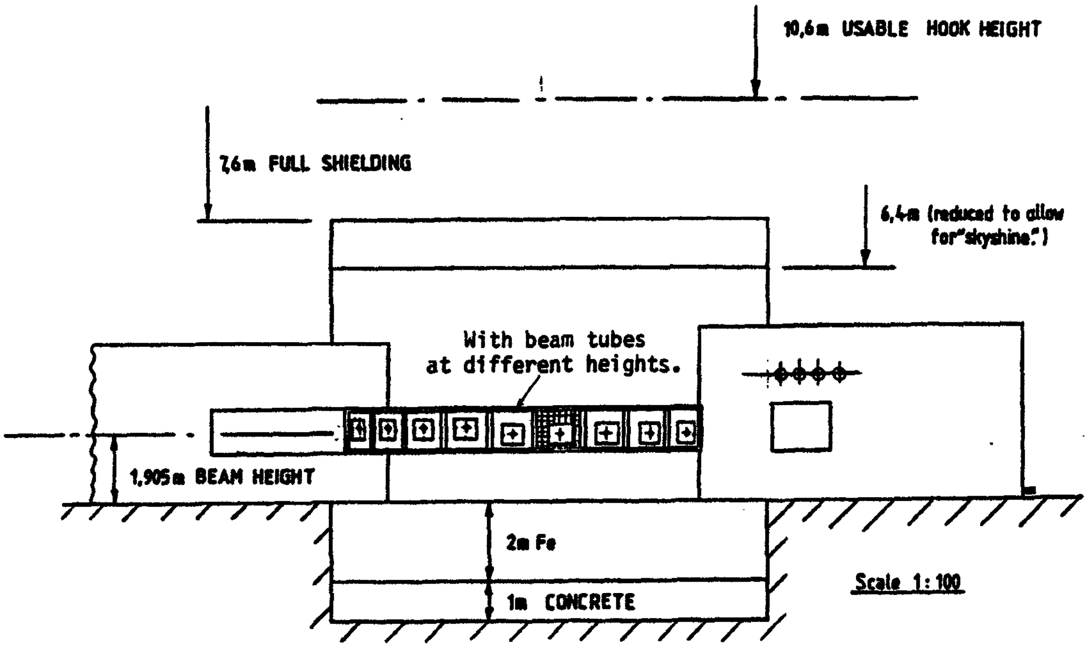


Fig. II-B.2. North side elevation of target station.

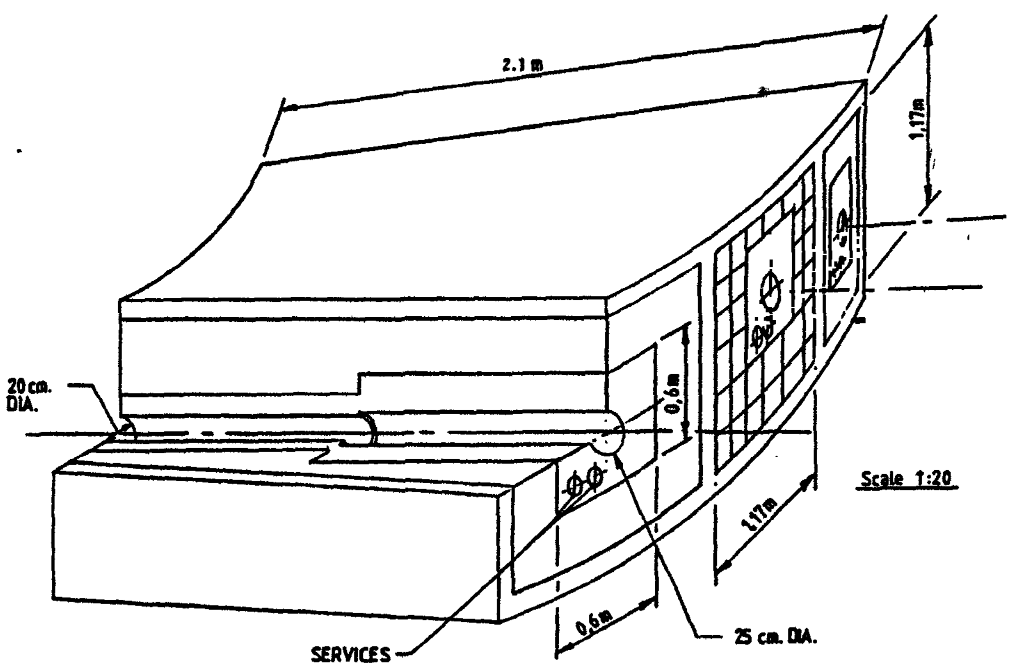


Fig. II-B.3. Cutaway view of a typical sector unit.

C. SNS Day-One Target/Moderator Configuration, A. D. Taylor, RL

The objective in drawing up the target-station design is to maximize the utilization potential by providing a diversity of neutron-scattering instruments (~ 20) and by covering a wide range of neutron-spectral regions, for example:

- high intensity
- high resolution, at the expense of intensity
- long wavelength, $\lambda > 4$ Å.

Taking into account the space available in the experimental hall and the target geometry required to remove 350 kW of heat, the four-wing geometry illustrated in Fig. II-C.1 has been adopted as the day-one layout.

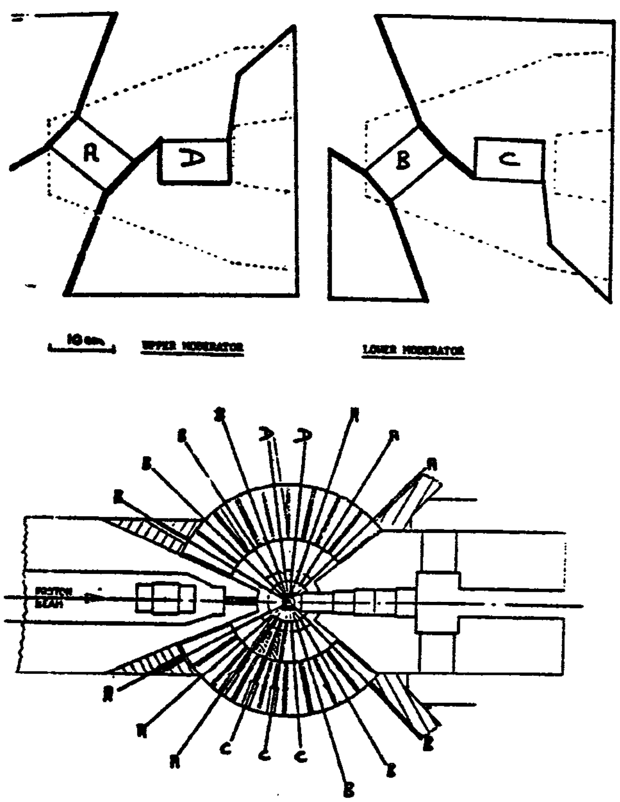


Fig. II-C.1. Initial beamline and moderator layout for SNS.

D. Physical Aspects of Cold-Moderator Design, A. D. Taylor, RL

During a discussion of the physical aspects of cold moderator design, the following points emerged:

- The principal aim in cooling a moderator is to extend the slowing down region, thus avoiding the complications in the behavior of the time pulse (and hence instrumental resolution) which occur with the onset of the maxwellian. This advantage has to be traded off against: a) the restriction of choice of moderator material, and b) the penalty imposed by the cryogenics on the geometric coupling between target and moderator.

- Candidate materials for a 20 °K moderator are liquid hydrogen and methane. The former has a low hydrogen density (ρ = 0.042 atoms $Å^{-3}$) which leads to poor coupling and broad peaks in the slowing down region. This increased leakage may be somewhat reduced in reflected systems. Tests on a liquid hydrogen moderator at ZING-P' are expected to take place in the early summer of 1979. Methane has a relatively high hydrogen density (ρ = 0.078 atoms $Å^{-3}$) and has low energy modes which aid rapid thermalization. It was suggested that the polymerization of methane, which has been attributed to radiation effects may result from the catalytic action of traces of the chlorinated solvents which are used as cleaning agents.

- Cold neutron moderators may be improved by the use of a reflector/filter, for example, polycrystalline beryllium for $\lambda > 4$ Å or a single crystal of beryllium or silicon which will operate over the entire thermal range.

- A TiH_2 moderator (ρ = 0.08 atoms $Å^{-3}$) will be built by the Rutherford Laboratory towards the end of 1979 for operation on the Harwell linac at both ambient and liquid nitrogen temperatures. Thermodynamic and radiation damage properties of this hydride at 77 °K have yet to be established.

- It was suggested that a comprehensive literature search be made for radiation and engineering behavior of potential pulsed-source moderator materials.

The reduction in coupling efficiency for a reflected wing moderator as a function of cryogenic gap has been estimated by a Monte Carlo method. The results are illustrated in Fig. II-D.1. The gap is defined to include both the vacuum space and the structural materials of the cryostat and moderator vessels. (The penalty is more dramatic for an unreflected system as shown by the dashed curve in Fig. II-D.1; the unreflected data were taken from LA-6020).

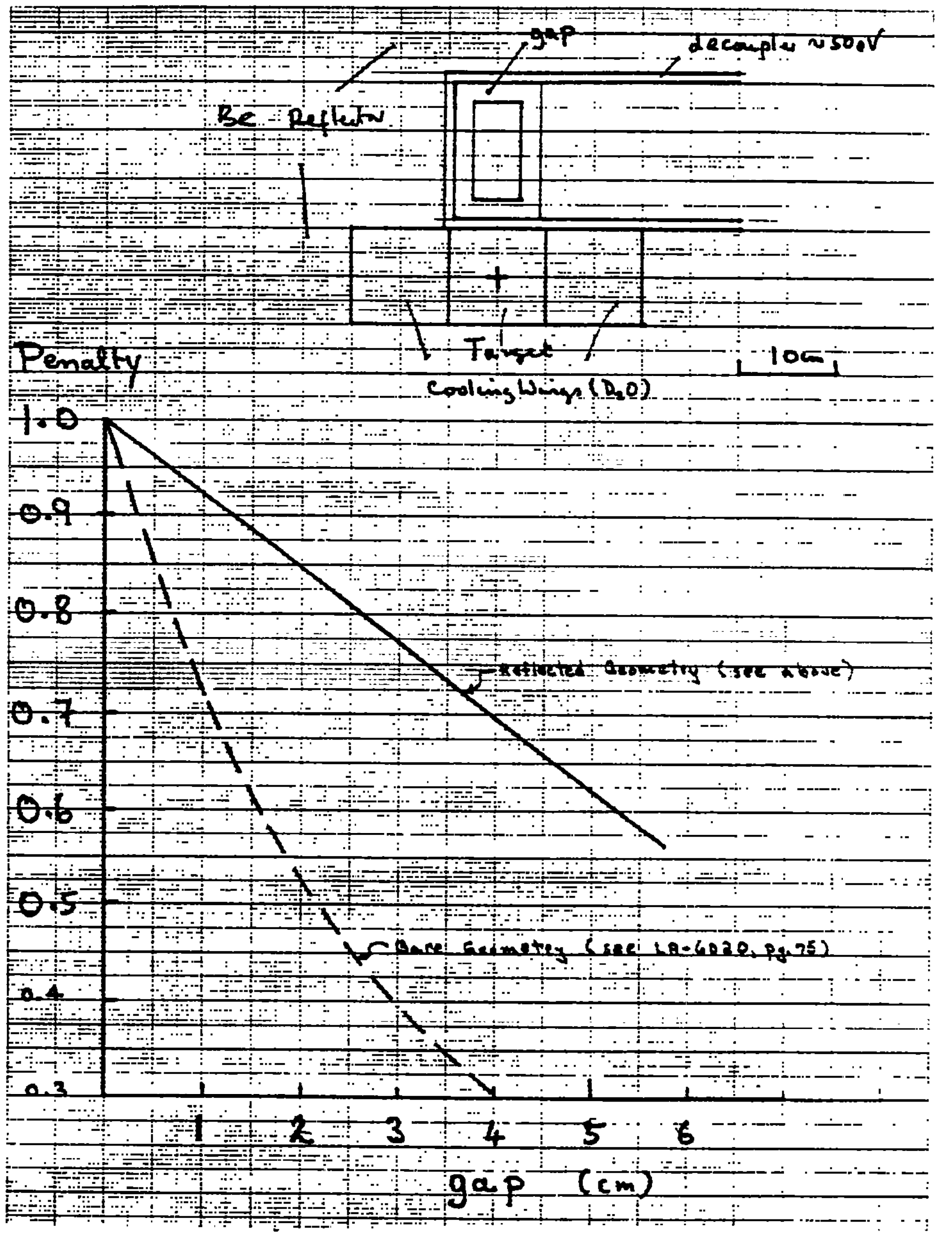


Fig. II-D.1. Illustration of penalty in moderator neutronics of varying the gap between the target and moderator.

E. Progress - SNS Neutron-Production Targets, R. W. Wimblett, RL

1. Schedule

The program for the provision of the SNS neutron-production target, services, and all associated equipment is:

1978/79	1979/80	1980/81	1981/82	1982/83
Conception & Establishing Parameters	Design	Manufacture	Installation	Commissioning & Operation

From the above schedule it can be seen that from the engineering viewpoint the year 1979 has been a year of schemes and computations to prove the practicability (or otherwise) of the mass of options considered during this period. All of the options were assessed and drawings are available for discussion if required. A decision has been made to use a segmented, doped or alloyed, uranium target using a 4 gap, channeled plate arrangement. The plates are to be cooled by D_2O using transfer of heat by forced convective nucleate boiling.

Next year will see the full detailed design of the target and all apparatus making up the target assembly such as, its services, monitors and controls.

2. Nucleate-Boiling Tests

A large number of nucleate-boiling measurements have been carried out on test elements to examine the sensitivity of "burn-out" to coolant velocity, temperature, and pressure. Of these test parameters, velocity proved to be critically sensitive; temperature and pressure were relatively insensitive in causing premature "burn-out" failure. A large number of tests have also been carried out to establish control and alarm values serving to provide safe operational control for the system. Graphs of the results of these tests are available on request.

3. Water-Flow Test

Water-flow tests have commenced on full-size target channels and these will be continued during the next few months. These tests are being made to:

- examine the shapes of target-plate entry and exit contours and the positioning of flow directors to insure even flow within any four-gap channel
- investigate the conditions applying within gaps and channels due to radiation and thermal cycling swelling in the uranium plates
- determine ways of reducing the pressure drop within the target assembly.

Tests are to be made to gather flow/pressure drop profiles for each of the channels within the target vessel.

4. Monitoring and Control

a. Flow/Pressure Drop Profile

The flow/pressure drop characteristic mentioned above will be used as the main indicator for uranium target-plate swelling in the operational target.

b. "Burn-Out" Warning

The overheating of any target plate will be sensed using noise monitoring. The onset of film boiling leading to "burn out" is accompanied by considerable vibrational noise (the steaming bottle effect) which will be monitored and the signal used to control flow and/or shut off the proton beam.

c. Target Parameters

The target parameters are as follows:

- peak-power density, 940 watts/cm^3
- peak-heat flux, 304 watts/cm^2
- water velocity, 3.2 metres/sec (10 ft/sec)
- water temperature, 38 °C
- pressure drop through plate gap, 0.05 bars (0.75 psi)
- thickness of peak-target plate, 6.5 mm of uranium, 0.25 mm of zircaloy cladding.

F. IPNS-I Target-Station Design and Engineering, J. R. Ball, ANL

The IPNS-I target stations are designed to meet the experimental program goals to the maximum extent possible. The IPNS-I facility consists of two experimental assemblies, one for neutron-scattering research and one for radiation-damage research. It is anticipated that the targets for these two assemblies will be of identical design. However, flux and spectrum measurements are currently being made on IPNS-I mockup assemblies at the ZING-P' facility to determine the most suitable target material for the radiation-effects facility. This summary will describe the design and engineering of the IPNS-I uranium target assembly and the neutron-scattering experimental assembly.

The IPNS-I target shown in Fig. II-F.1 is made up of 4-inch diam, 1-inch thick uranium discs clad on all surfaces with 0.020 inch of Zircaloy 2. Eight of these discs are stacked together with cooling channel spacers between the discs to form the target assembly. The assembly is housed within an outer vessel of stainless steel which serves as a coolant pressure and containment vessel. The target heat load of 20 kW is removed by circulating demineralized light water across the flat surfaces of the target discs. The heat is released via a primary-to-secondary heat exchanger.

The IPNS-I target design has been analyzed for thermal and stress responses using a combination of high-energy neutron transport calculations (HETC) to determine spacial energy deposition, thermal transport calculations (THTB) to determine temperature distributions and elastic stress analysis (MARC/CDC) to determine the resultant stresses. The IPNS-I design basis proton beam is 5×10^{12} protons/pulse at 30 Hz and 500 MeV. The particle distribution is assumed to be parabolic with a FWHM of 4.0 cm. The results of this analysis indicate that the maximum operating centerline temperature is 275 °C. This peak temperature occurs on the target axis 6 cm from the front target face. The elastic stresses were evaluated for the worst case target disc where the temperature is 275 °C at the center and drops radially and axially to a wall temperature of 80 °C. The resultant stresses from such an analysis show that yield stress of the uranium may be exceeded by 20% at the point of maximum stress. The stresses in the Zircaloy cladding reach only about 60% of the yield stress. Limiting the maximum uranium temperature to 275 °C will insure that "ratchetting" growth will not occur. Calculations of uranium growth due to nuclear interactions, i.e., gas formation, cavitation swelling, etc., indicate that such growth will not be lifetime limiting. The most probable mechanism for ultimate target failure appears to be cracking of the Zircaloy cladding due to fatigue resulting from thermal cycling of the target. Such cycling results from the startup and shutdown of the proton beam and not from the pulsed nature of the beam. It is estimated that the target lifetime will be at least 10^4 cycles.

A solid uranium target 3.25 inches diam by 6 inches long has been successfully clad with 0.060 inch of Zircaloy using the process of High Temperature Isostatic Pressing (HIP). The target shown in Fig. II-F.2 was fabricated at Argonne and shipped to Battelle, Columbus Laboratories for HIP bonding. The bonding process involved heating the assembly to 840 °C and applying 15,000 psi externally. These conditions were held for three hours followed by a slow cool (~ 2 °C/minute) to 500 °C and 12,000 psi. These conditions were held for one hour for stress relieving. The unit was then cooled slowly to ambient. Ultrasonic inspection of the bonding interface indicates the presence of a perfect diffusion bond over all of the clad surfaces.

An important consideration in maintaining the integrity of the target is maintaining the proton beam within acceptable limits. This is particularly true of beam diameter. Calculations show that a beam of less than 3.5 cm FWHM for an extended duration could cause premature cladding failure.

The design of the target cooling system is based on a coolant velocity of 15 ft/s with an inlet temperature of 49 °C. A static pressure of 20 psig at the target outlet insures a factor of ~ 3 between the burnout heat flux and the calculated maximum heat flow.

The target assembly is housed within a two-region cylindrical reflector of beryllium. The overall reflector assembly is shown schematically in Fig. II-F.3. Figure II-F.4 is a vertical section of the inner reflector region. Four moderators are arranged within this region in a "wing" geometry with the target. Two rectangular moderators below the target provide the source neutrons for nine neutron-beam tubes. A third rectangular moderator above the target is viewed by three more beam tubes. A cylindrical moderator above the target provides a dedicated source of ultracold neutrons which travel vertically upward through a beryllium filter to the top surface of the biological shield. All of the moderators will be designed to be cooled to 20 °K and could contain either liquid or solid moderator materials. The inner reflector assembly is designed to be removable for modification or replacement with a different geometry.

The neutron-scattering reflector assembly is housed in a cavity within the biological shield. Figure II-F.5 shows the layout of the biological shield. The 12 horizontal neutron-scattering beam tubes are arranged symetrically around the reflector with an angular separation of 18°. Provisions are made within the shield for an experimental proton beam and two horizontal, multipurpose neutron beams at ± 15° from the forward direction. The basic shield composition is ~ 12 feet of iron in the forward direction and ~ 8 feet of iron at 90°. An outer layer of concrete and absorber material serves as a thermal neutron absorber and gamma shield. The biological shield is designed for a dose rate of 0.5 mrem/h. Figure II-F.6 is a vertical section through the biological shield showing a typical neutron-beam tube. The minimum beam-tube size is 10 inches by 18 inches to accommodate beam plugs with apertures viewing the moderators in either the wing or slab geometry. The figure also shows a concept for the equipment cavity and beam gate.

At the interface of the concrete and steel of the biological shield is a metal liner which forms a gas-tight volume within which the atmosphere can be controlled. It is important to eliminate air from the cracks and joints of the stacked steel shielding. Thermal neutron irradiation of such air results in the production of ^{41}Ar and the formation of nitric acid (if the air contains moisture). A low pressure helium atmosphere will be maintained within this enclosed volume to prevent these problems.

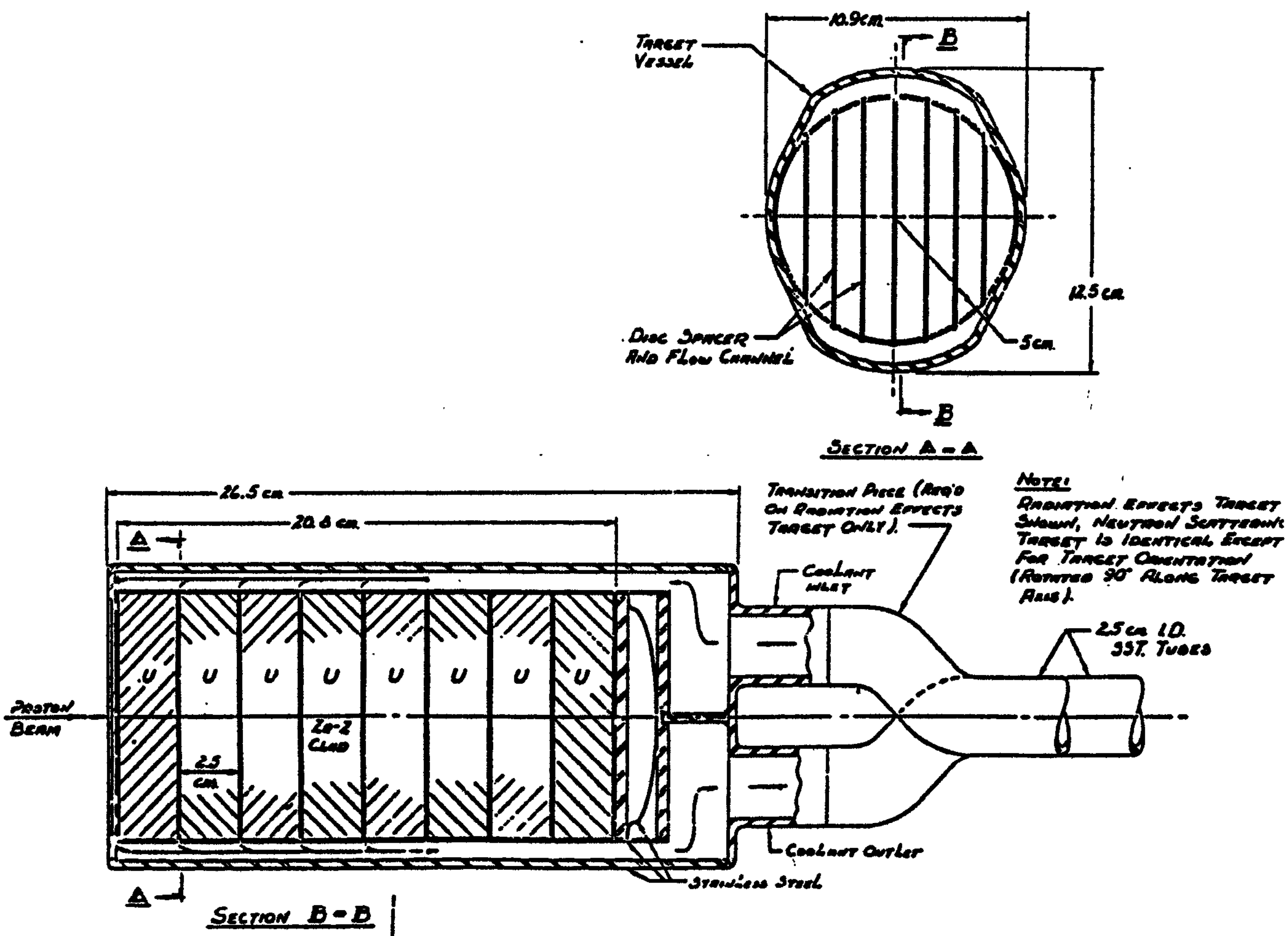


Fig. II-F.1. IPNS-I target assembly conceptual design.

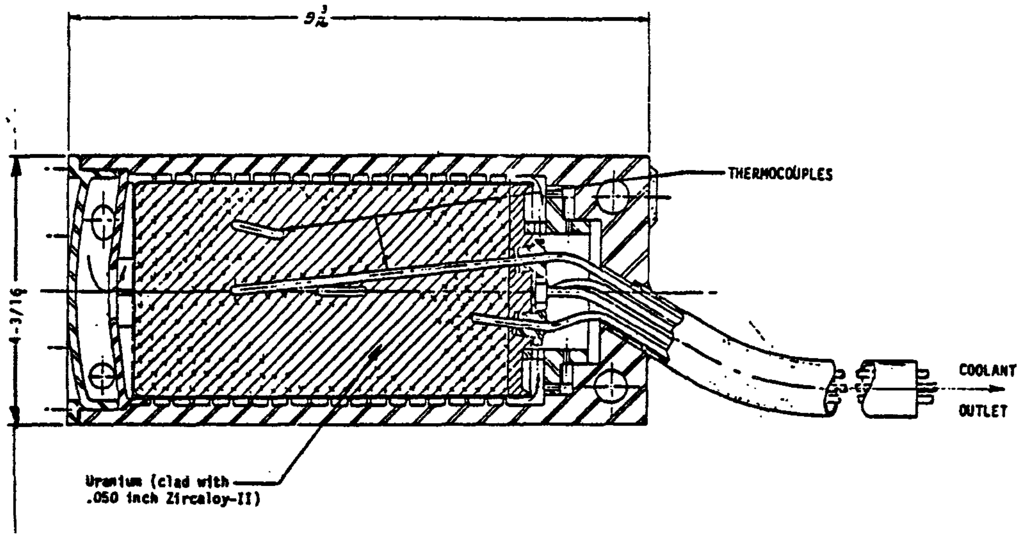


Fig. II-F.2. ZING-P' uranium target assembly.

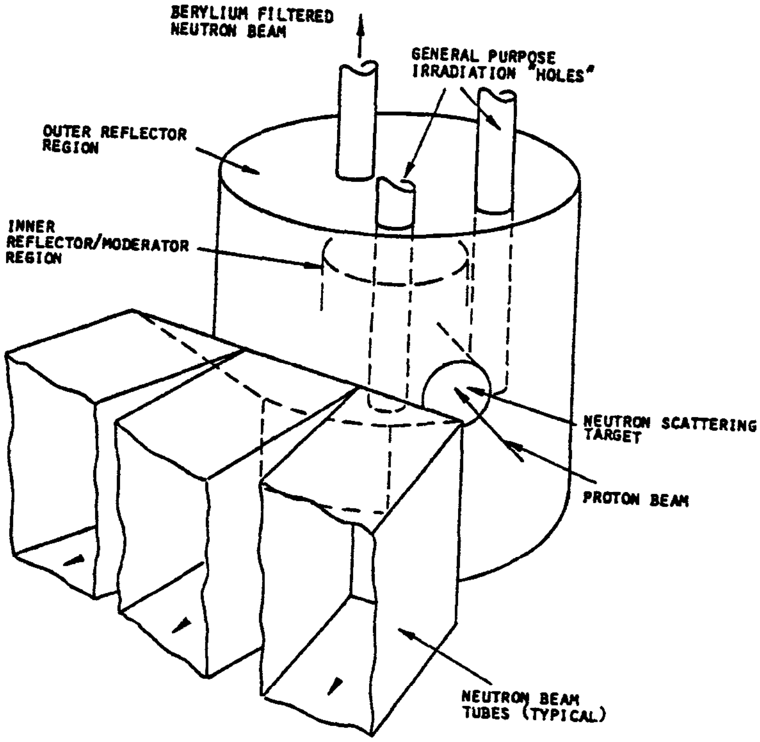


Fig. II-F.3. IPNS-I neutron scattering experimental assembly.

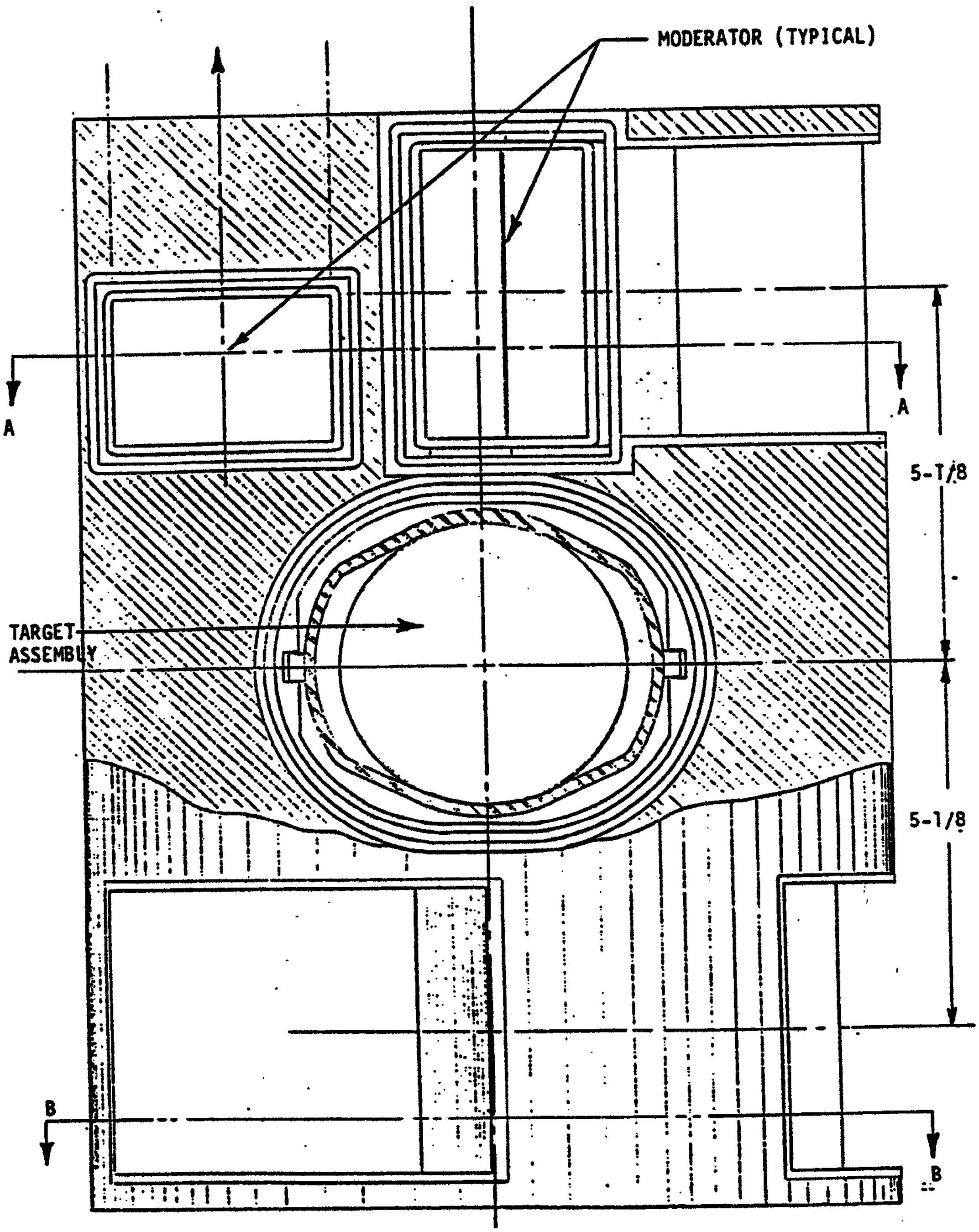


Fig. II-F.4. Inner reflector region of IPNS-I neutron scattering experimental assembly.

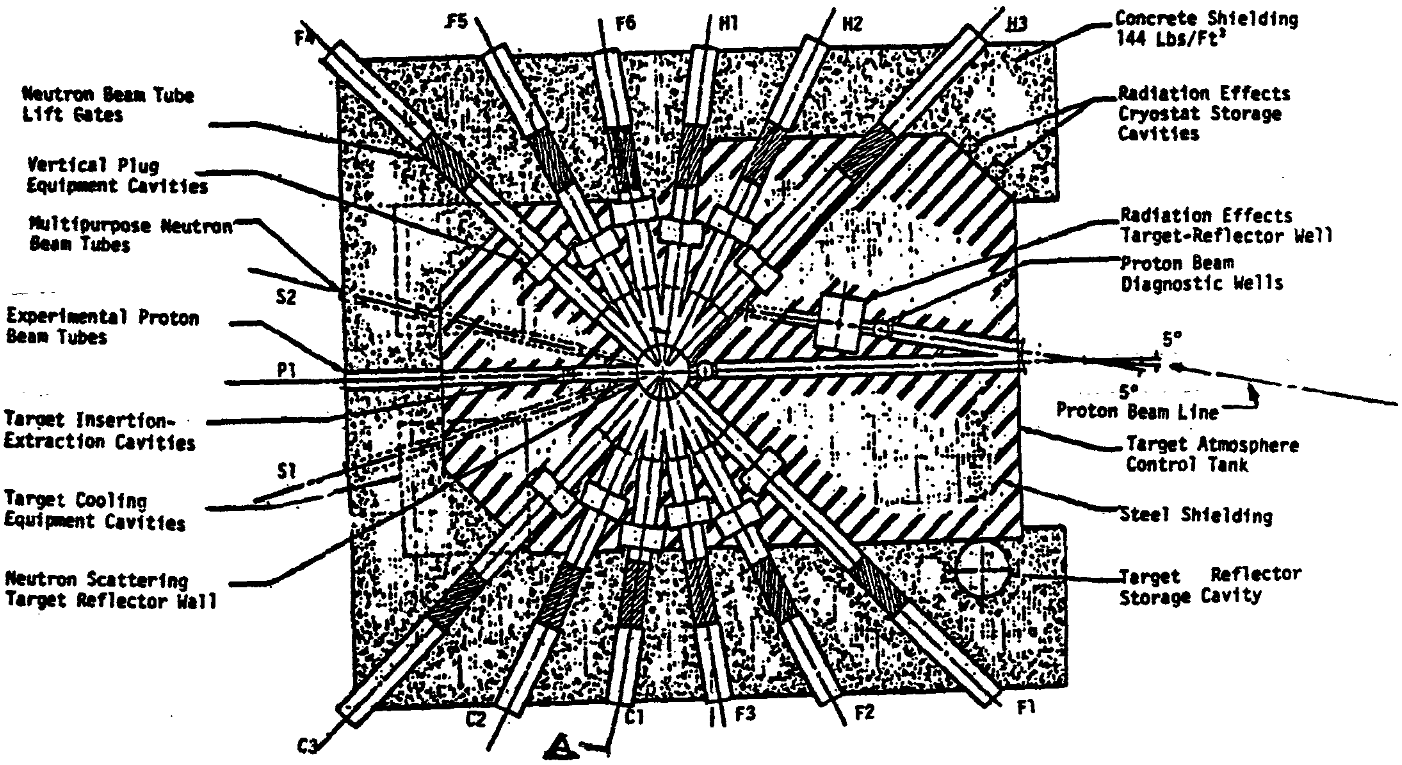


Fig. II-F.5. IPNS-I biological shield layout.

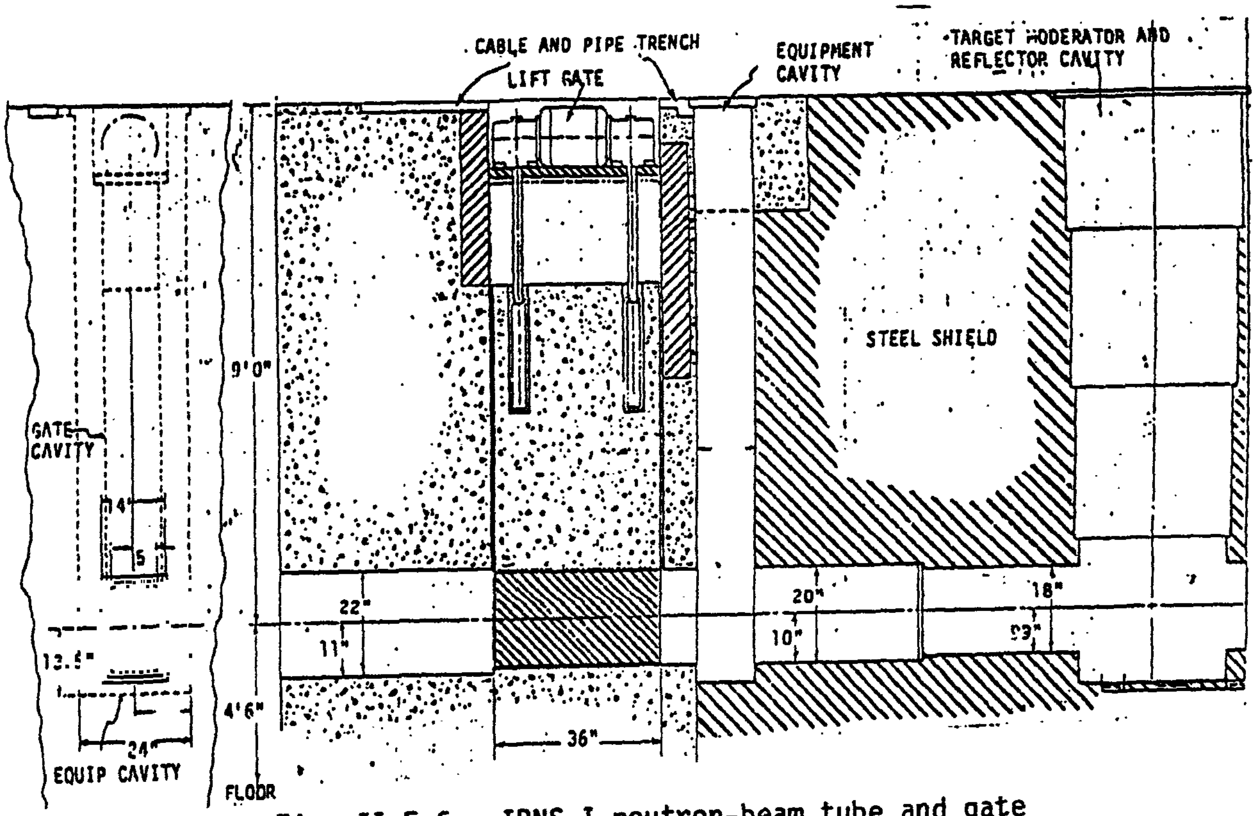


Fig. II-F.6. IPNS-I neutron-beam tube and gate arrangement - conceptual.

G. IPNS-I Neutron-Scattering Facility, Experimental Requirements, J. R. Ball, ANL

The design of the IPNS-I neutron scattering facility is based on meeting the goals of the neutron-scattering program and other experimental needs to the maximum extent feasible. These goals can be categorized as:

- geometry and layout
- neutronics
- flexibility
- versatility.

The specific requirements in each of these areas will now be discussed in more detail:

1. Geometry and Layout

The facility shall be capable of supporting up to 12 scattering instruments simultaneously with neutron flight paths ranging from ~ 5 m to ~ 50 m. The 12 beam tubes should view the moderators at an angle $\geq \pm 45°$ from the forward direction of the proton beam. There should be a vertical neutron-beam tube looking at a dedicated ultracold moderator. For the base design, all moderators should be laid out in a "wing" geometry so that no scattering beam tube views the target directly. Equipment cavities should be provided in each horizontal beam tube, as close to the moderators as possible, for installation of choppers or other experimental components.

2. Neutronics

A design objective is to provide maximum peak neutron flux at the face of each moderator. The moderator neutron pulses shall exhibit a minimum of pulse broadening from external sources such as reflected neutrons and delayed target neutrons. Compromise between these incompatible requirements shall be made according to specific instrument requirements.

3. Flexibility

Although the base design calls for the moderators to be arranged in a "wing" geometry with respect to the target, the facility design should provide for changing the target/moderator configuration to a "slab" geometry for any or all of the horizontal moderators. It is recognized that such a change would constitute a major modification and therefore the facility need not be designed to provide this flexibility in routine operation. Provision should be made for operating any or all moderators as cold (~ 20 °K) moderators with solid or liquid moderator materials. A desirable feature of the design would allow the target to be positioned axially with respect to the moderators to selectively peak the neutron flux to a given moderator.

3. Versatility

Capability to provide for experimental needs other than neutron scattering should be accommodated wherever feasible. Provision should be made for proton irradiation experiments. Additional multipurpose neutron beams should be accommodated as may be feasible. Such beam tubes may fall within the ± 45° forward direction sector. Thermal-neutron irradiation facilities (≥ 2 inch inside diameter) with time averaged fluxes > 1×10^{12} $cm^{-2} \cdot s^{-2}$ should be provided where feasible.

H. Remote-Handling Considerations for IPNS-I, N. J. Swanson, ANL

The activities associated with the handling of radioactive materials for IPNS-I are divided into two distinct categories. These are: a) the proton synchrotron and its beam-transport system, and b) the target/moderator/reflector systems for the neutron sources.

For the accelerator systems no remote handling systems, per se, are to be used. However, techniques used for remote handling applications will be applied for particular devices. These techniques will be used to permit easy and quick removal of items anticipated to require replacement. Replacements may be needed due to malfunction or failure and for improvement purposes. Included will be the application of quick disconnects for electrical connections, control and monitoring equipment, vacuum seals, water cooling piping, mounting and positioning mechanisms, and other similar devices. Shadow shields will be used for direct contact approaches by maintenance personnel. The degree of application of special techniques will be related to susceptibility for change. For example, the extraction system magnet of the Rapid Cycling Synchrotron has displayed frequent failures and contributes to poor proton extraction efficiency. Frequent changing of this magnet is expected for an indefinite period. Air pallets may be employed to assist in the removal of heavy items such as magnets.

For the target/moderator/reflector systems, the designs will include features for easy removal into shielding casks. The removal system will be as simple as possible. Removed radioactive items will be transferred to hot cells, via the casks, where remote handling can be performed efficiently with proper equipment. One of the most important factors involved with this approach is for proper communication between the IPNS personnel and the hot-cell people during the design periods. These communications are essential so that the hot-cell people can become suitably prepared for the anticipated remote handling and possibly post irradiation examination or repair activities.

I. Neutron-Beam Currents as a Function of Proton Energy and Target Diameter in a Pulsed-Spallation Source, J. M. Carpenter and T. G. Worlton, ANL

As is well known, the total number of neutrons produced by spallation increases roughly linearly with proton energy. However, the distribution of neutrons produced in the target becomes more extended as the proton energy increases, since the cascade builds up at small angles from the incident end of the target. The total number of neutrons produced also diminishes as the target diameter is made smaller, since fewer secondary neutron-producing reactions can then take place. Offsetting this is the fact that moderators can be coupled more efficiently to small-diameter sources than to large ones.

Calculations of these effects were done recently at Argonne, using the HETC code to transport high-energy particles, and the VIM code to transport neutrons to low energies. The targets were modeled as NaK-cooled U disks, 1.2 times as long as the proton range, and of variable diameter. An annular void of 1-cm width separated the target from the moderators, which were surrounded with a Be reflector and (except for moderator "C") decoupled by boron layers. The Be reflector radius was kept equal to the target length or 30 cm, whichever was greater. The arrangement is shown in Fig. II-I.1.

Table I shows the resulting epithermal beam current per unit lethargy, evaluated at 1 eV, $EI_p(E)_{1\ eV}$ on a per-proton basis. Results were developed for the average of the four moderators, and for the highest-intensity moderator ("C"). The results for the average moderator are shown in Fig. II-I.2.

As can be seen in Fig. II-I.2, when the proton energy is increased, the beam intensity increases approximately linearly up to nearly 2 GeV, at which energy the anticipated diminishing return is evident. The results also indicate that the beam current diminishes only slightly with increasing target diameters, in the range of diameters studied.

These conclusions apply specifically to the pulsed-source geometry studied, but similar effects would be evident in other arrangements, although the diminishing return on increased proton energy may set in at higher or lower energies.

Of course, the extended length of the source might be exploitable by use of larger moderators, or of a larger number; these possibilities have not been explored.

Table I

NEUTRON YIELDS CALCULATED BY HETC AND VIM

E_p (MeV)	Diam (cm)	n/p	$\left(EI_p(E)_{1\ eV}\right) \times 10^3$	$\left(EI_p(E)_{1\ eV}\right) \times 10^3$ Moderator C
500	6	11.67	4.36	7.07
	8	12.55	3.93	6.09
	10	13.37	3.91	5.77
	12	13.59	3.46	5.50
800	6	22.69	7.94	12.20
	8	24.38	7.77	11.75
	10	26.04	7.60	10.31
	12	28.11	7.58	11.12
1200	6	34.15	11.29	17.02
	8	38.89	11.08	14.63
	10	41.62	11.22	16.52
	12	45.81	10.85	16.06
1800	6	51.16	16.20	23.97
	8	57.49	16.51	24.63
	10	62.37	14.72	20.68
	12	68.06	14.98	21.50

The beam current $EI_p(E)_{1\ eV}$ is in units of n/p·sr.

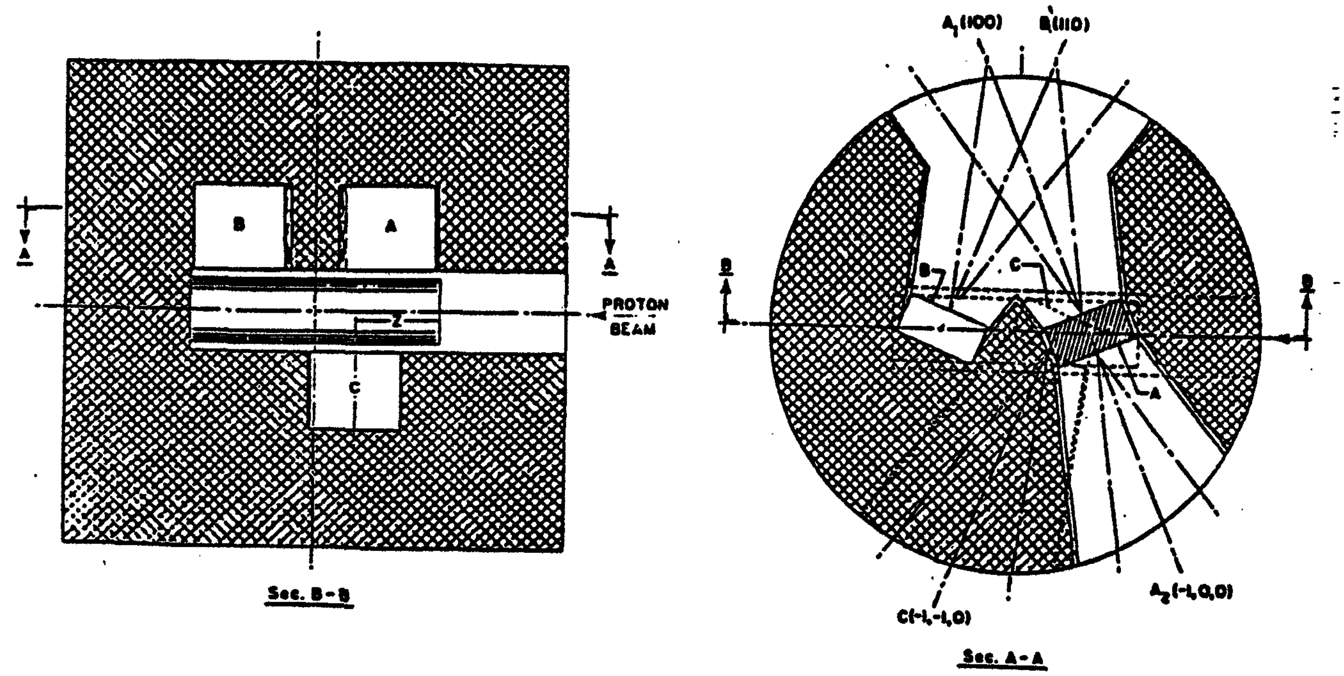


Fig. II-I.1. Arrangement of target, moderators, and reflector for the VIM calculations. The distance, Z, between the front of the target and the centerline of moderator C was determined from the average axial position of the neutrons produced in the HETC calculation. The heavy lines in the figure indicate $^{10}B_4C$ lining of the beam tubes and moderator sides. The cross hatched area is Be reflector. Beam directions from the moderator surface are indicated by lines on either side of the normal to the moderator surface.

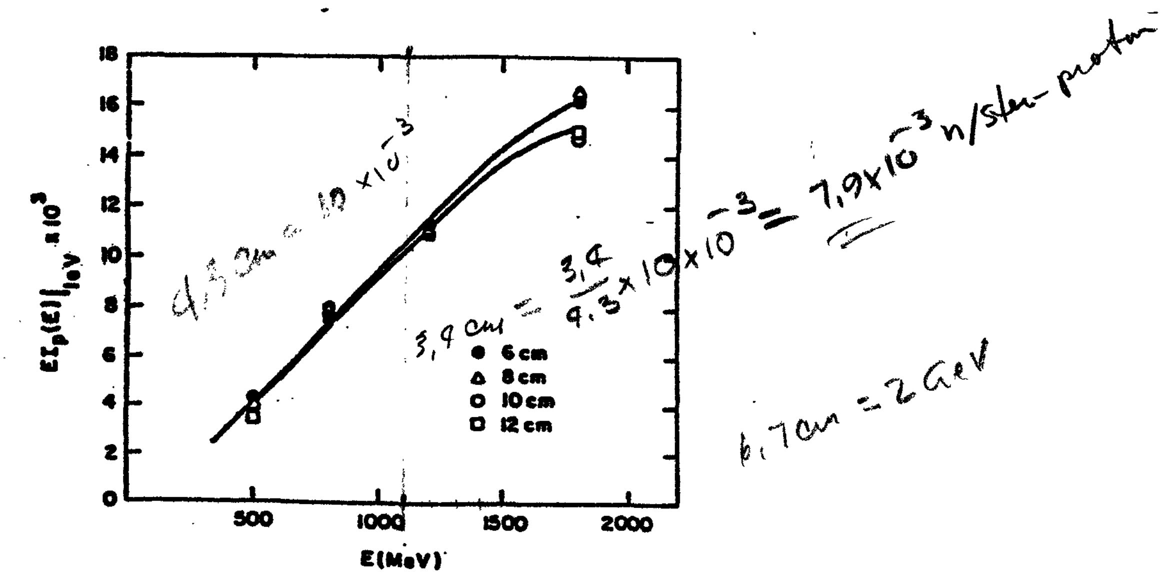


Fig. II-I.2. The energy dependence of the neutron-beam current at 1 eV for the average of the three moderators studied. Results of the HETC and VIM calculations have been corrected for fission below 15 MeV and for neutron leakage in HETC. $EI_p(E)$ is in units of neutrons per proton per steradian.

J. Delayed Neutron Background in Pulsed Spallation Neutron Sources, J. M. Carpenter, ANL

When fissionable material (for example ^{238}U) is used as a target in a pulsed spallation neutron source, delayed neutrons are produced from certain "precursor" fission fragments which decay by neutron emission following beta decay. The decay half-lives range from a few tenths of one second to about one minute. When the interpulse time is short by comparison with these decay times, delayed neutrons constitute a nearly steady source of neutrons (unless there exist yet-undiscovered, shorter-lived precursors) between source pulses. Although their energies are smaller (~ 0.5 MeV) than those of fission, evaporation, or cascade neutrons, one may assume that they are moderated and emerge in neutron beams with roughly the same probability as prompt source neutrons. Figure II-J.1 indicates how these delayed neutrons produce a background in a neutron beam.

At distance D, prompt neutrons from the source pulse spread out according to wavelength, arriving to produce a time distribution which reflects the wavelength distribution. Delayed neutrons of all wavelengths arrive continuously at D.

The magnitude of the delayed neutron background can be estimated by comparing the average rate of arrival of prompt neutrons ("signal", S) to the rate of arrival of delayed neutrons ("background", B). The ratio is equal to the ratio of the number of prompt neutrons produced by the source, to the number of delayed neutrons. In ^{238}U, the delayed-neutron fraction from fission is about 1.5%. In a ^{238}U spallation source, about half the neutrons are produced from fission so that the fraction of neutrons which are delayed is about 0.75%. Thus, the ratio S/B is about $1/.0075 \approx 130$.

Such a background is likely to be troublesome in only a few classes of measurement; in those cases it may be necessary to reduce the delayed neutron background by use of a chopper close to the source. In that case, the delayed neutron background would be reduced by the duty cycle of the chopper.

These comments do not apply to the interpulse neutrons which might be produced by fissions induced by low-energy neutrons. This would occur if there were fissile material in the target, as in natural uranium, or in the case in which Pu is allowed to build up in the target.

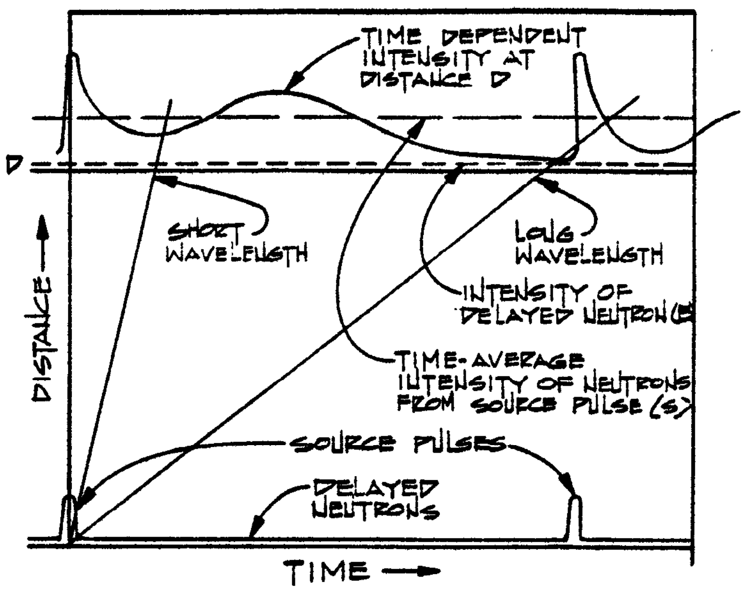


Fig. II-J.1. Illustration of how delayed neutrons produce a background in a neutron beam from a pulsed spallation neutron source.

K. Beam Port and Shutter Design at the WNR, H. Robinson, LASL

The beam ports that penetrate the WNR target 1 shield are 3.7-m long and are fabricated from carbon steel stepped pipes ranging in size from 26-cm to 59-cm diam.

When not in use, these ports are plugged with a blank beam plug consisting of 3.1 m of steel, 10 cm of polyethylene, and an outer canister of 30 cm of magnetite concrete. These ports and the target crypt are operated in a vacuum of ~ 25 microns.

The first collimator installed in the bulk shield was a drilled set of blank beam plugs with a vacuum window installed on the outside of the shield. When not in use, a 1.4-m-long brass rod is inserted into the plug. Any changes for this collimator require shutting off the proton beam.

The five remaining collimators have moving shutters or liquid filled canisters which can be drained and refilled while operating.

A typical example of the collimators used at the WNR would be the one installed on the Small Angle Scattering Experiment, Flight Path #12 (see Fig. II-K.1). The front step has a 15-cm-long collimator wheel fabricated from tungsten-boron-carbide; the collimator has six appertures ranging in size from 0.3-cm to 2.9-cm diam. This wheel is driven with an offset mechanical shaft from the back of the plug. The remainder of this step is filled with a fixed-hole collimation. The second and third steps have a fixed hole collimation located in a rotatable shutter. The shutters are geared to a 2:1 ratio for closure from the back of the plug. The plug is fabricated from carbon steel.

The collimator plugs at the WNR have ranged in cost from $5 K to $75 K. In an attempt to reduce the cost of these units, a universal design is being considered.

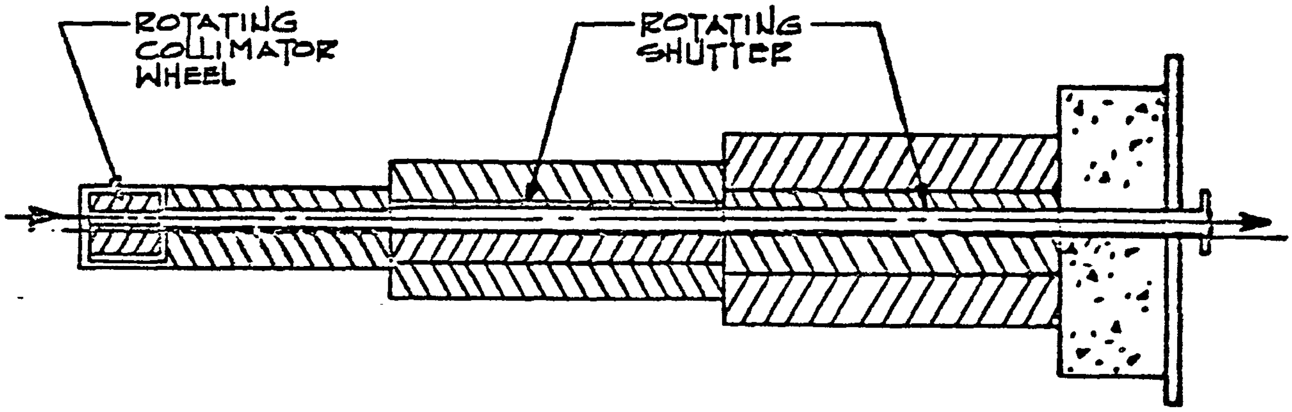


Fig. II-K.1. Flight path #12 beam plug at the WNR.

L. Neutron Radiation Detection at Pulsed Spallation Neutron Sources, R. J. Buchanan, LASL

1. Introduction

At ICANS-III, a lot has been said about new intense neutron source facilities being proposed and built around the world. I would like to address the problems of personnel radiation safety in the following areas:

- How will the neutron radiation dose rates be monitored around the source and in particular, when it is a pulsed source in the ns or μs range?
- What levels of radiation are we working with?
- How will the approximate neutron spectrum be determined over such a wide energy range (thermal to 800 MeV)?
- How will access to the flight paths and experimental areas be controlled?

2. Neutron Dose Rate Monitoring

Generally, commercial instruments are not compatible with beam parameters around pulsed neutron sources because of their long detector resolving time compared to the width of the neutron pulse. Therefore, a system was developed at LASL which has proven to provide a satisfactory answer to the neutron dose rate measurement problem (see Fig. II-L.1). This instrument is called an Albatross IV Portable Pulsed Neutron Radiation Survey Instrument. The Albatross IV is a revised version of the Albatross III developed at Fermi-Lab. The Albatross IV uses a microcomputer and digital electronics instead of the analog system used in the Albatross III. This allows for a much more versatile and easier to calibrate instrument.

The detection system for the Albatross is a 0.25-mm-thick Ag foil wrapped around a GM tube that is located in the center of a 25-cm-diam polyethylene pseudosphere. The neutrons are thermalized in the moderator and then captured by ^{109}Ag to form ^{110}Ag plus a γ-ray. the ^{110}Ag beta decays with a half-life of 24.4 s. There is also a second GM tube wrapped with tin that is used to subtract counts due to γ-rays created in the moderator and also external gamma fields. The β^- plus the γ-ray counts from the Ag wrapped G-M tube and the γ counts from the Sn wrapped G-M tube are sent to a microcomputer where they are manipulated to give the net counts due to neutrons. This information is accumualted in bins for a predetermined time interval which can be varied between 15 s and 8 min.

The meter reads directly in mrem/h when the neutron energy spectrum being detected is approximately the same as the neutron energy spectrum of the neutron source used to calibrate the instrument. Because of the integrating nature of the silver foil and microcomputer program, the response of the instrument is independent of the beam's repetition rate and/or pulse width.

The Albatross IV shows the same energy dependence as other 23-cm and 25-cm diameter polyethylene-moderated neutron survey instruments such as the PNR-4 and Model 6. Such instruments over respond to low-energy neutrons and under respond to high-energy neutrons (see Fig. II-L.2). When calibrated using PuBe neutrons they read correctly within approximately ± 50% in neutron fields with average neutron energies of 0.5-14 MeV.

3. Radiation Levels at the WNR

Although radiation levels will vary greatly depending on the facility, an idea of what radiation levels we are working with at the WNR is shown in Fig. II-L.3. With 19 nA on a thin Al target (simulating a beam spill) the neutron dose rates were in the neighborhood of 20-40 mrem/h through 4 to 8 feet of concrete and 50-100 mrem/h through 2 to 4 feet of steel. The dose rates due to thermal neutron, which were approximately equal to the higher energy neutron dose rates, are also of concern outside of the steel shielding.

4. Neutron Energy Spectrum

The point was brought out that the high-energy component of the neutron spectrum may be contributing some additional dose which is not being fully detected by the Albatross IV, because it is calibrated using PuBe neutrons. Preliminary neutron-energy spectra and average neutron energy measurements have been made and it is believed that a large error is not being introduced by the higher energy neutron component. Work is presently in progress to determine more clearly the neutron energy spectrum from thermal to 800 MeV and, therefore, the correct neutron dose rates.

Fig. II-L.1. Front view of Albatross IV pulsed neutron survey instrument.

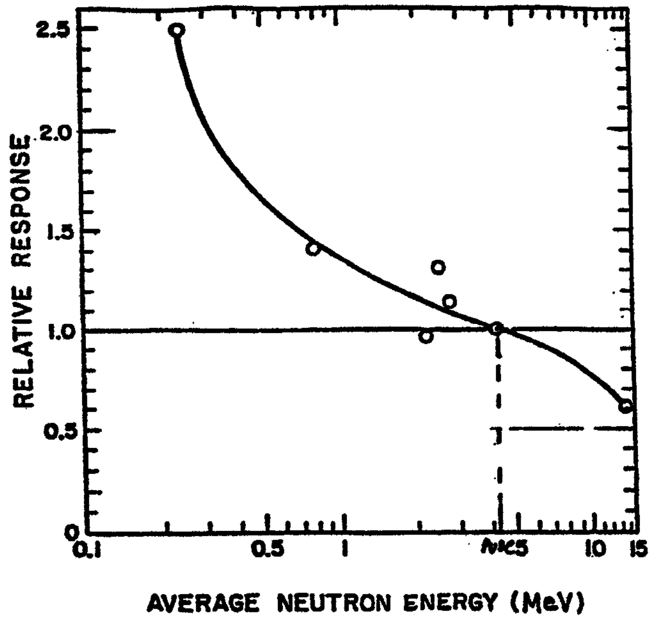


Fig. II-L.2. Relative response of polyethylene-moderated neutron survey instruments as a function of neutron energy.

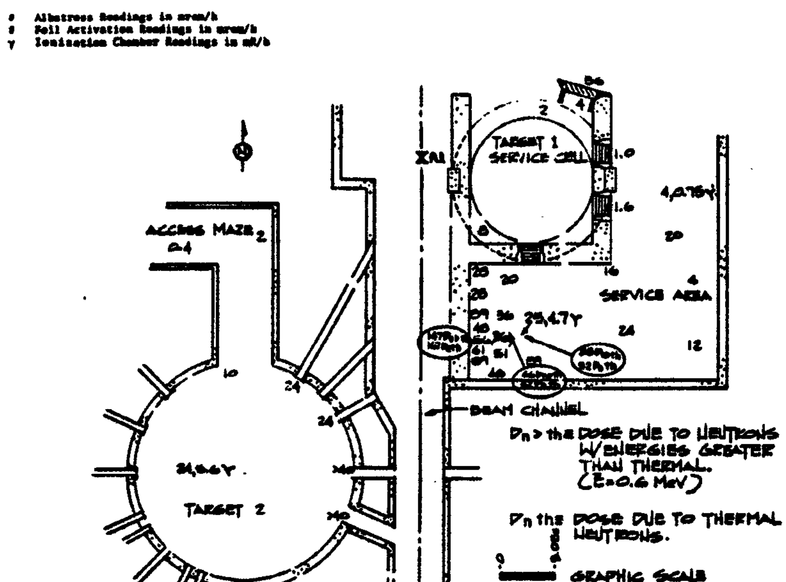


Fig. II-L.3. Measured neutron and γ-ray dose rates at the WNR for 19 nA of protons striking a thin Al target in the beam channel.

M. Neutronics of the WNR Target/Moderator Relevant to Beam-Plug Design, G. J. Russell, LASL

Monte Carlo calculations have been made, for the present WNR target/moderator geometry, which are relevant to the subject of beam plug design for the high-current target (target 1) at the WNR. Measurements of the spatial distribution of the neutron surface flux from the target 1 water moderator have also been made; a summary of the results follows.

1. Effects of the Size of Collimation

The size of the collimation in a flight path alters the "field-of-view" which a detector or sample sees on the moderator surface. The magnitude of the effect depends on the energy of the neutrons of interest (see Fig. II-M.1). The calculated results shown are for a 6.5-cm-thick by 20-cm-high by 30-cm-wide CH_2 moderator surrounding the WNR Ta target. As can be seen in Fig. II-M.1, the number of neutrons leaking from the moderator surface does not vary directly as the ratio of areas viewed because of the spatial distribution of leakage neutrons. The 15-cm-diam (177 cm^2) "field-of-view" represents the maximum practical size neutron beam which can be extracted from target 1. The 11.3-cm-diam (100 cm^2) "field-of-view" represents a "standard" area quoted by other laboratories when describing moderator neutronics.

2. Effects of Lowering the WNR Moderator

The effects of flight-path neutronics resulting from lowering the moderator centerline relative to the nominal flight-path centerline were studied by moving a 100 cm^2 "field-of-view" vertically up the moderator surface. The effects are energy dependent and are illustrated in Fig. II-M.2. For example, for a 100 cm^2 "field-of-view " the lowering of the moderator centerline by 2.54 cm causes the neutron-beam intensities to decrease by 6.6% to 12% for the energies shown; the thermal neutron-beam intensities should closely follow the 1 eV neutron leakage.

3. Effects of a Shadow Plate

The effectiveness of a shadowplate for removing the high-energy neutrons from a moderated neutron beam was calculated. The "field-of-view" on the CH_2 moderator was first limited to 177 cm^2 and then further reduced by a variable-width shadow plate as shown in Fig. II-M.3. The results of the calculations are shown in Figs. II-M.4 and II-M.5, and depend on the neutron energy of interest and the energies of the neutrons which are considered to cause background problems.

4. Measured Spatial Distribution of Neutron Surface Flux

The spatial distributions of the neutron surface flux from the unpoisoned H_2O moderator in Al cans was measured using bare and Cd-covered Au foils. The WNR Ta target was centered vertically relative to the moderator. The results are shown in Figs. II-M.6 and II-M.7. The thickness of the H_2O was 7 cm.

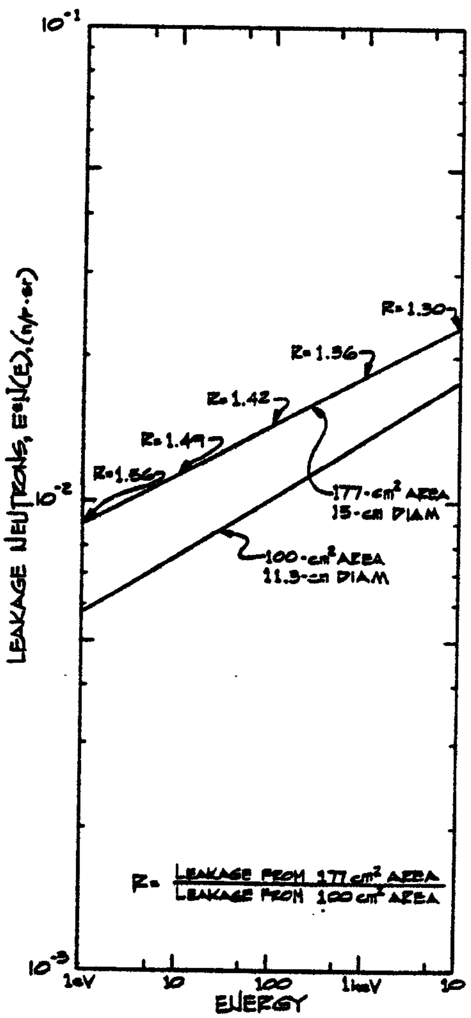


Fig. II-M.1. Calculated energy-dependent neutron beam leakage as a funtion of the "field-of-view" on the moderator surface.

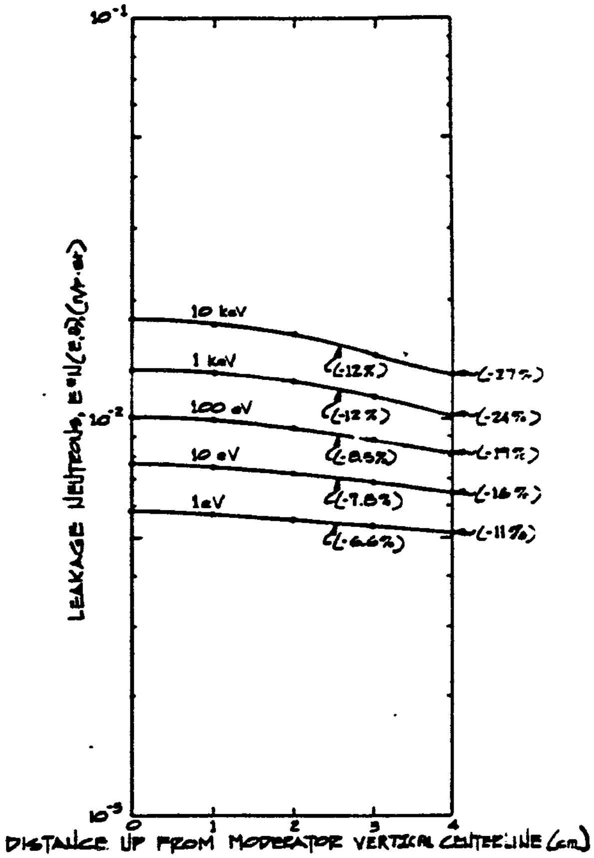


Fig. II-M.2. Calculated effect on neutron beam leakage of raising the "field-of-view" on the moderator surface. The percentages in parenthesis are relative to the "field-of-view" centered about the moderator centerline.

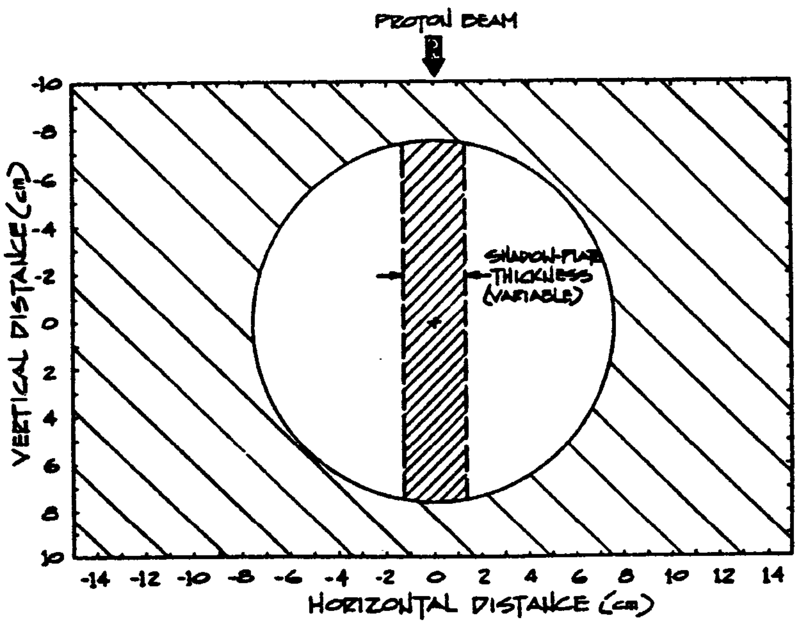


Fig. II-M.3. Illustration of first limiting the "field-of-view" on the moderator surface by collimation and then restricting the "field-of-view" further by use of a shadow plate.

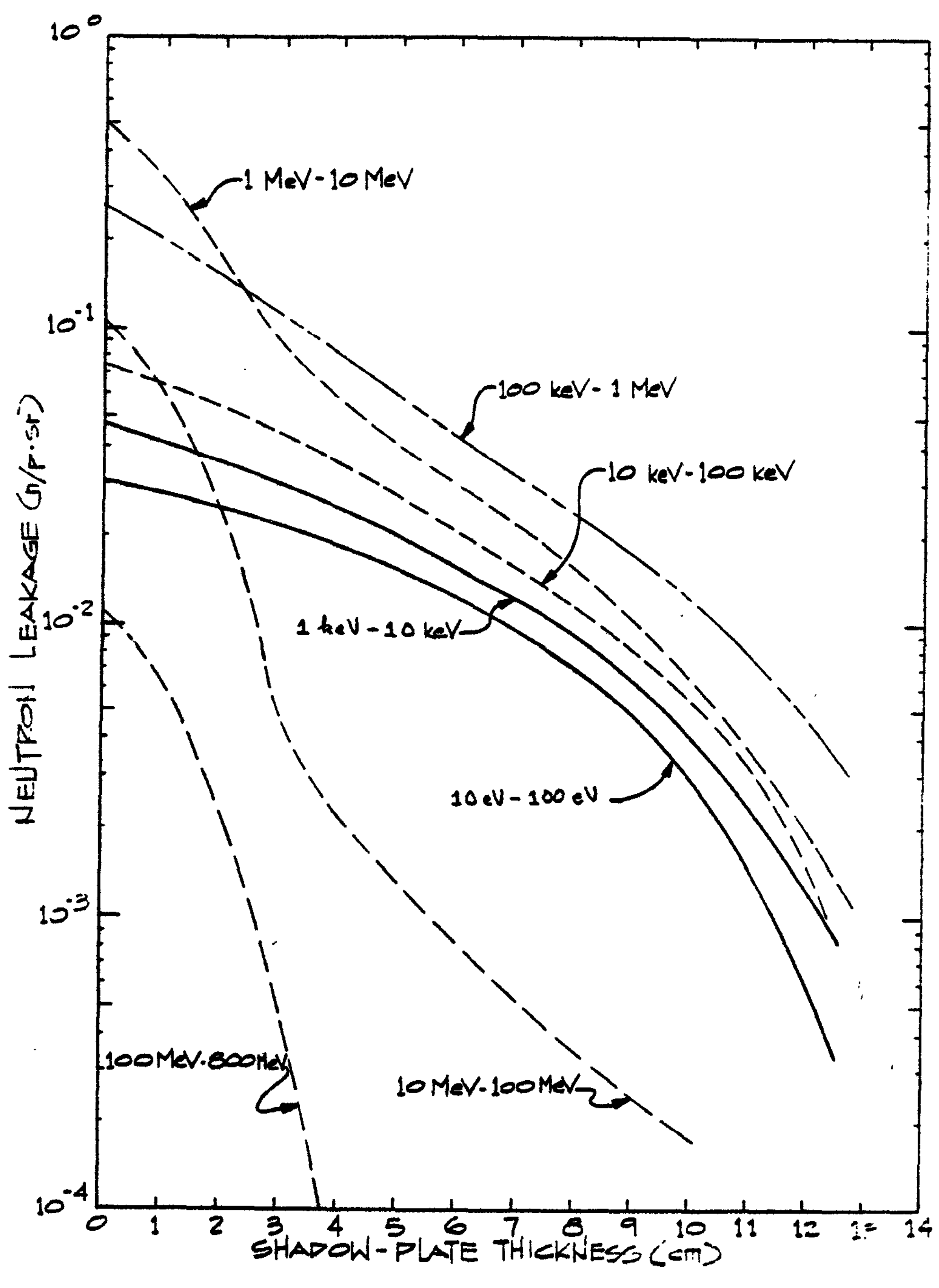


Fig. II-M.4. Calculated effect on neutron beam leakage of varying the thickness of a shadow plate. The solid lines represent potential neutrons of interest and the dashed lines possible neutron background contributors.

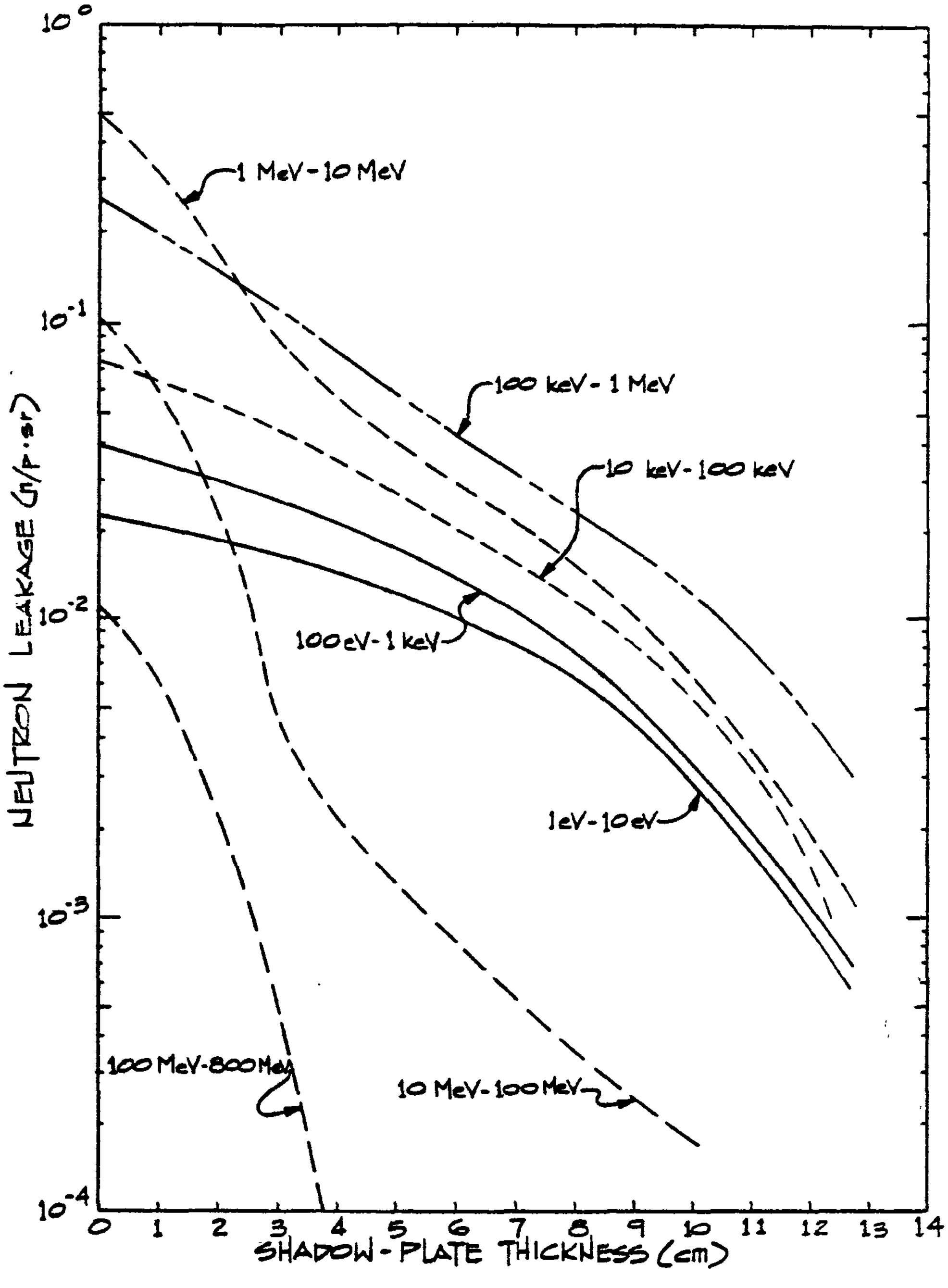


Fig. II-M.5. Calculated effect on neutron beam leakage of varying the thickness of a shadow plate. The solid lines represent potential neutrons of interest and the dashed lines possible neutron background contributors.

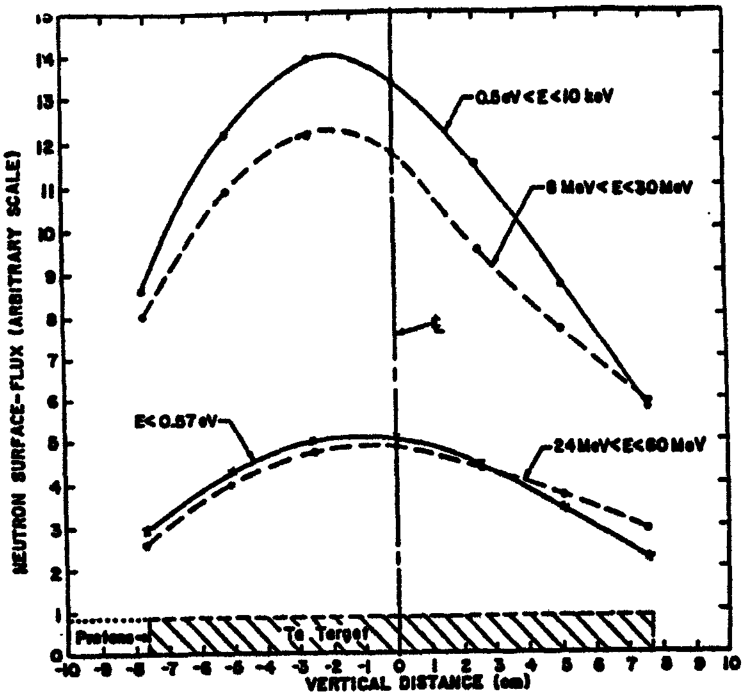


Fig. II-M.6. Measured vertical distributions of the neutron surface flux from the 20-cm by 30-cm surface of the WNR H_2O moderator. The measurements were made along the axis of the target.

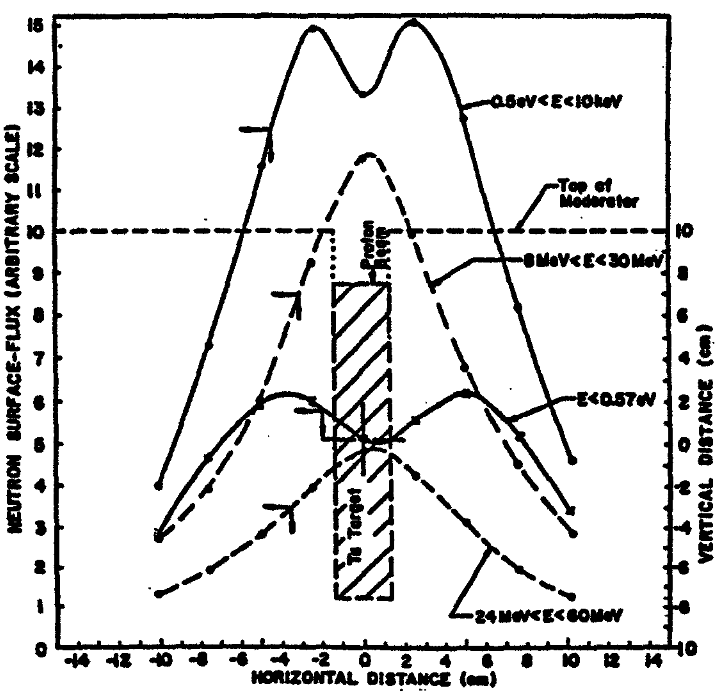


Fig. II-M.7. Measured horizontal distributions of the neutron surface flux from the 20-cm by 30-cm surface of the WNR H_2O moderator. The measurements were made along the moderator centerline. The left axis shows the neutron surface flux and the right axis shows the vertical size of the target/moderator configuration.

N. Comments on the Choice of a Slab or Wing Geometry for a Pulsed Spallation Neutron Source, W. Kley, ISPRA

It is known that in steady-state heavy water reactors, the thermal neutron flux is identical in radial or tangential beam tubes if the end of the beam tubes are positioned approximately at the same radial distance from the core, but the signal to background ratio is 100 times better in the tangential beam. Therefore, one does not have to pay a penalty in terms of thermal neutron flux. However, in pulsed-neutron sources this is not the case. Yoshikazu Ishikawa and Noboru Watanabe[1] have measured the thermal neutron conversion efficiency, defined by $n_{th}/sr{\cdot}n_f$, where n_f is the neutron source intensity, for a number of moderator/reflector systems. The results are summarized in Table I; the data were obtained using an Am-Be neutron source.

The data in Table I have been enumerated for the case where the center of the Am-Be source has been centered at a distance of 2 cm from the moderator surface (as indicated in Fig. II-N.1).

We see that there is a penalty of about a factor of two by choosing a totally reflected wing geometry. It can be expected that the penalty may be even a factor of three or four if a totally reflected slab geometry is used as indicated in Fig. II-N.2.

The question of whether or not this penalty has to be accepted depends actually not only on the signal (thermal neutron flux) but also on the signal to background ratio S/B for the two cases. In order to compare the two cases one has to use a figure of merit.[2]

$$M = \frac{T_2}{T_1} = \left(\frac{S_1}{B_1}\right)\left(\frac{B_2}{S_2}\right)\left(\frac{S_1}{S_2}\right)\frac{\left[\frac{S_2}{B_2} + 2 + 2\sqrt{\frac{S_2}{B_2} + 1}\right]}{\left[\frac{S_1}{B_1} + 2 + 2\sqrt{\frac{S_1}{B_1} + 1}\right]}$$

where T_2 and T_1 are the corresponding measuring times for the two cases in order to obtain the same statistical accuracy. Since we are dealing with a pulsed neutron source we can suppose that after about 100-200 μs the very fast neutrons have died away and that the S/B ratio will be very similar for the two cases. If this can be proven experimentally, then the choice for a slab geometry is obvious. In any case we can install and phase background rotors that guarantee the equality of the S/B-ratio for the two cases.

References

1. Y. Ishikawa and N. Watanabe, "KEK Neutron Source and Neutron Scattering Research Facility," KEK-78-19, A/I (November 1978).

2. W. Kley, "Design Criteria for Moderators and Beam Tubes for Spallation Neutron Sources," EUR-62-2e (November 1978).

TABLE I

COMPARISON OF NEUTRONICS FOR DIFFERENT TARGET/MODERATOR GEOMETRIES

Unreflected slab-geometry	10 x 10 x 5 cm^3 A = 100 cm^2	15 x 15 x 5 cm^3 A = 225 cm^2	25 x 25 x 5 cm^3 A = 625 cm^2
Thermal neutron conversion efficiency ($n_{th}/sr \cdot n_f$)	1.5×10^{-3}	3.5×10^{-3}	6.2×10^{-3}
Reflected wing-geometry	3.5×10^{-3}		

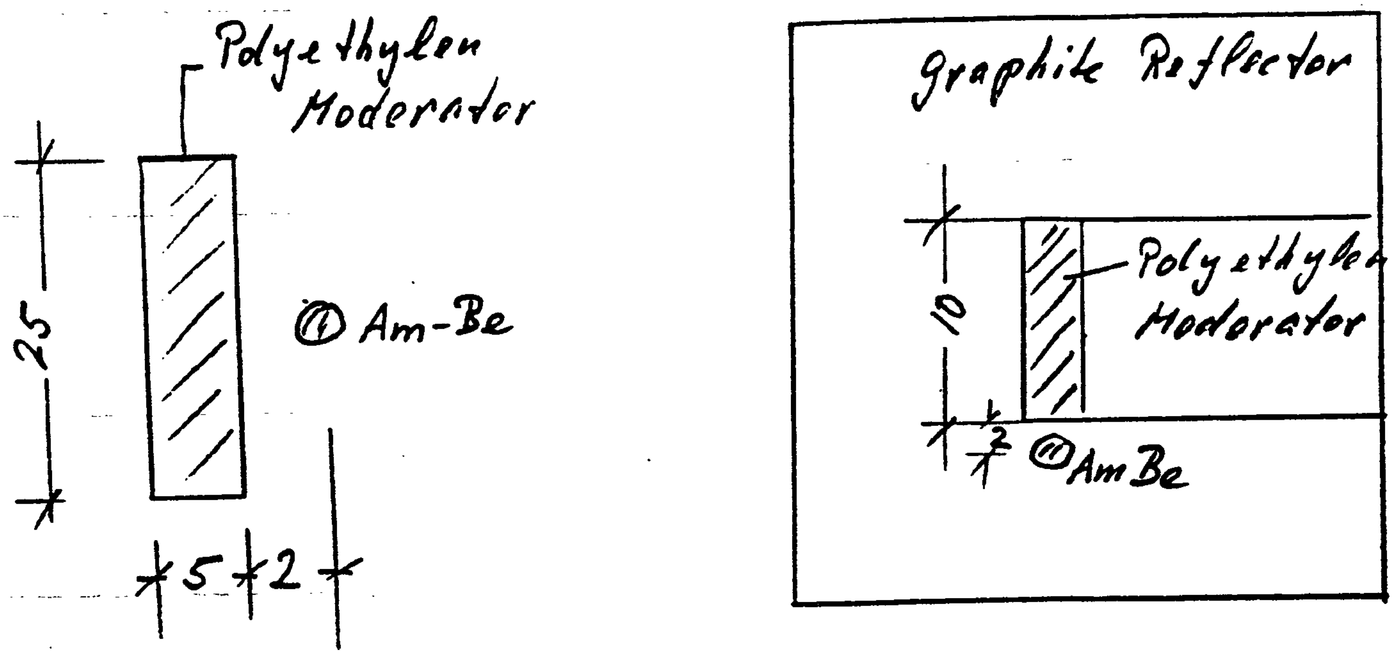


Fig. II-N.1. Slab and reflected-wing geometry. The dimensions are in cm.

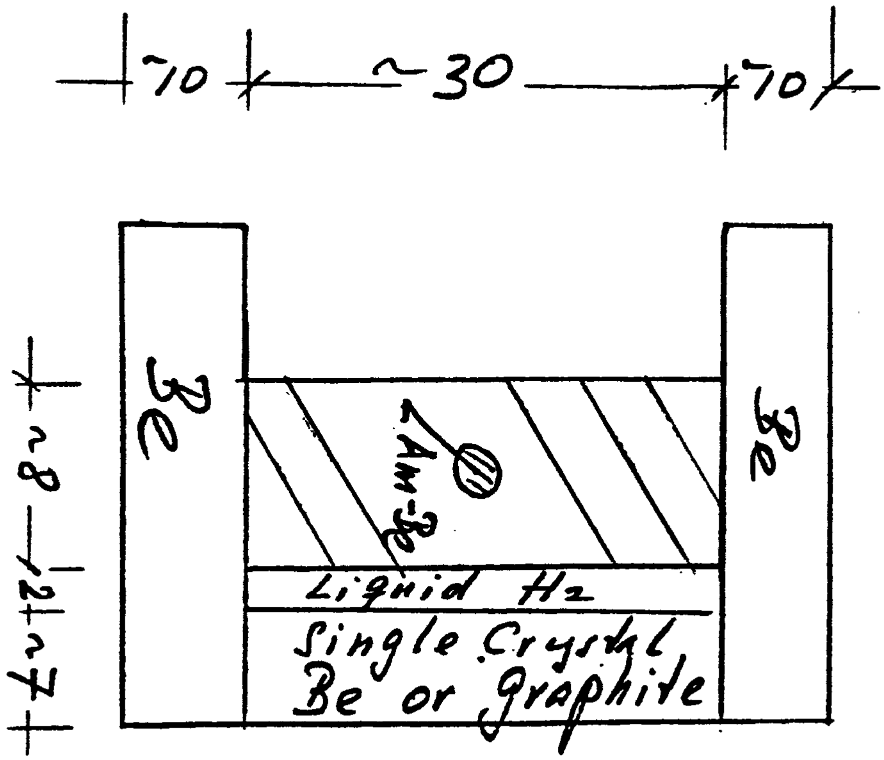


Fig. II-N.2. Reflected-slab geometry. The dimensions are in cm.

0. Remarks on the Thermal Power in a Cold-Neutron Source at the Proposed SIN Spallation Source, W. E. Fischer, SIN

In a reactor, the γ-rays from a multiplying core give a considerable contribution to the heating of a cold source. This implies that such a source is normally placed a certain distance from the reactor core, that is, in a region where the flux is not maximal. In a spallation reaction, the energy of the γ-rays produced per neutron is ~10 times smaller. If the ratio of target-to-beam diameter is large enough and the chamber of a Pb-Bi target is 10 cm (as considered for the SIN source) these γ-rays will be absorbed in the target itself. We therefore assume a cold neutron source near to the target in the region of maximum thermal neutron flux. The main contributions to the heating come from:

- cascade neutrons (we assume the cascade protons also to be absorbed in the heavy metal target)
- gammas from neutron capture in the material of the source and its surrounding.

Let us assume a spherical cold source with a volume of 30ℓ, in the region of maximum thermal neutron flux (see Fig. II-0.1). The containment consists of two spherical shells of 4-mm Al or Zircalloy each, with the space between the two shells being evacuated. The inner shells shall be filled with liquid D_2 at a temperature of 20 °K. This source corresponds roughly in its material composition to the cold source of the ILL reactor in Grenoble.[1]

1. Contribution from Cascade Neutrons

We assume an angular distribution and an energy spectrum of cascade neutrons from Monte Carlo calculations, as given in Ref. 2. Knowing the material composition of the source, we calculate the energy deposition by fast neutrons in the inner shell of the containment and in the liquid D_2. For a primary proton current of 1 mA, we obtain a heat deposition of 280 W by fast neutrons.

2. Contribution from Capture Gammas

This power is proportional to the thermal flux in the region of the source. Since the material composition is similar to the one at the ILL source, we take the results of the ILL calculations[1] and scale them down to our thermal neutron flux. For the thermal neutron flux, which corresponds to a 1 mA primary proton current, we obtain 620 W of heating by capture γ-rays.

Therefore, the total power dissipated in this cold source adds up to 900 W per 1 mA proton current, with 50% being deposited in the inner containment shell and 50% in the liquid D_2. Such a cold source could be operated with an external power of approximately 250 kW. We hope that a primary proton current of 2-3 mA (600 MeV) could provide us with a cold-neutron source which is competitive with the strongest sources available today.

References

1. P. Ageron, R. Ewald, H. D. Harig, T. Verdier, Energie Nucleaire, 13, 15 (1971).

2. R. R. Fullwood, J. D. Cramer, R. A. Haarman, R. P. Forrest, R. G. Schrandt, Los Alamos Scientific Laboratory report LA-4789 (January 1972).

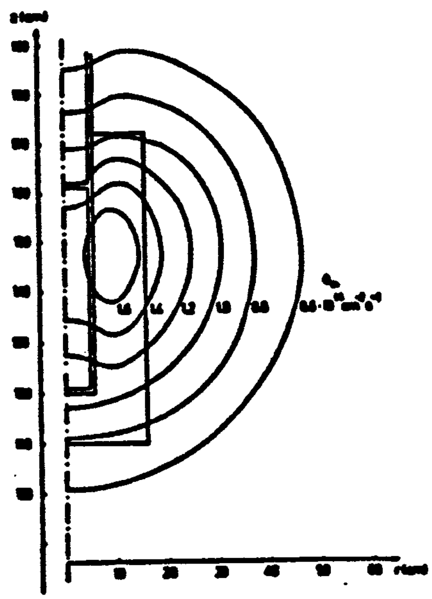


Fig. II-0.1. Flux lines for constant thermal neutron flux.

P. Remarks on the Conceptual Design of the D_2O Moderators at the Proposed SIN Spallation Source, W. E. Fischer, SIN

The Be sleeve as an inner part of the reflector gives a somewhat higher flux (5-10%) due to (n,2n) reactions of neutrons with higher energy and a flatter radial neutron flux distribution. The corresponding cross sections are however not well known. The influence of this sleeve will be investigated in a mockup experiment at SIN by an SIN-Julich-Karlsruhe collaboration. In the same experiment, neutron flux depressions of beam tubes will be determined.

Further moderator geometries have been investigated by Beat Sigg (ETH-Zurich).[1] From these calculations the following conclusions can be drawn:

- A smaller radius of the D_2O-tank leads to lower thermal neutron flux. Typically, a reduction of 80 cm decreases the neutron flux by 20%.

- It is possible to replace the external part of the D_2O moderator by H_2O without considerable depression of the thermal neutron flux around the Be sleeve.

References

1. Studie uber eine Kontinuierliche Spallations Neutronenquelle am SIN, W. E. Fischer, Ch. Tschalar (SIN); B. Sigg (IRT-ETHZ); H. Rauch (Atomina Oestess. Hockschulen Wien).

Q. Comments Relevent to the Design of TRIUMF, I. M. Thorson, TRIUMF

1. Experimental Requirements/Basis for Target/Moderator Optimization Criteria for the TRIUMF TNF

The ground rules for TRIUMF TNF design, in rough order of priority were:

- It had to have a very high availablity factor as a dump for the residual beam from the main meson production line.

- It had to serve as a thermal neutron irradiation and beam facility equally.

These specifications were, at least, colored by the fact that our accelerator facility is, and has the prospect into the indefinite future of, being operated in the continuous wave mode.

2. On the Pros and Cons of Uranium as a Target Material (Point Not Enumerated During ICANS-III

The hazard to experimenters doing elastic neutron scattering from delayed neutrons is probably not very great; the hazard to inelastic neutron scattering experiments is much greater.

R. Target/Moderator Optimization, M. Barbier, MITRE Corp.

Although the progress in pulsed-neutron source design has been remarkable, the target/moderator configuration is an area where work can be particularly rewarding. One hears talks of ever increasing proton beam currents and people today envision from hundreds of μA to tens of mA.

With the proton beam size growing, the target and cooling systems dimensions will increase and so will the distance at which one can place the moderators. At some point the neutron beam quality might not increase any more given the materials properties. With present-day technology, there could be an optimum reached with the best design depending only on the materials used. Finding whether this optimum exists and where it lies seems an important task. To achieve this one could:

- determine categories of users having similar needs in terms of beams
- optimize for each category according to particular needs such as brightness of source, angular resolution, time resolution, energy range, number of beams, or simply intensity
- include in the optimization process, target dimensions as well as moderator configuration.

This work will lead to the best target/moderator assemblies for the basic needs of the users community, and allow a determination as to whether there is a physical limitation in going to higher proton beam currents and target sizes, given by the neutron beam quality required.

S. Alternate Shielding Study for IPNS-I, M. Barbier, MITRE Corp.

The following considerations were used for this design study of the IPNS-I shield:

- make shield dismountable
- reduce iron volume
- absorb penumbra (radiation coming at a slant angle through beam tubes)
- make beam shutters adequate to absorb radiation coming from the target when in sight with slab geometry
- avoid having to pierce iron for choppers, equipment, filters, etc.

Figure II-S.1 shows the shield construction.

The iron was concentrated near the source, the shutters were incorporated in the neutron beam line shielding. The radiation scattered when the cascade neutrons hit the beam shutter is tertiary radiation, that is, low-energy; the cascade particles emitted in the 90° direction are low-energy with the most probably energy at 90° being 45 MeV. Also, the source strength is small (less than 10^{-6} of the cascade particles from the target).

The slots are a design suggestion to permit lowering equipment without piercing holes. They must be plugged with some iron on top of the equipment.

Figure II-S.2 shows the penumbra shield and beam gate when the target is below beam line. The penumbra shields consist of 1 ft. of iron slabs placed above (or below) the beam line, when the target is below (or above) it. They can be used as beam shutters when they are above, because beam shutters should always be lowered.

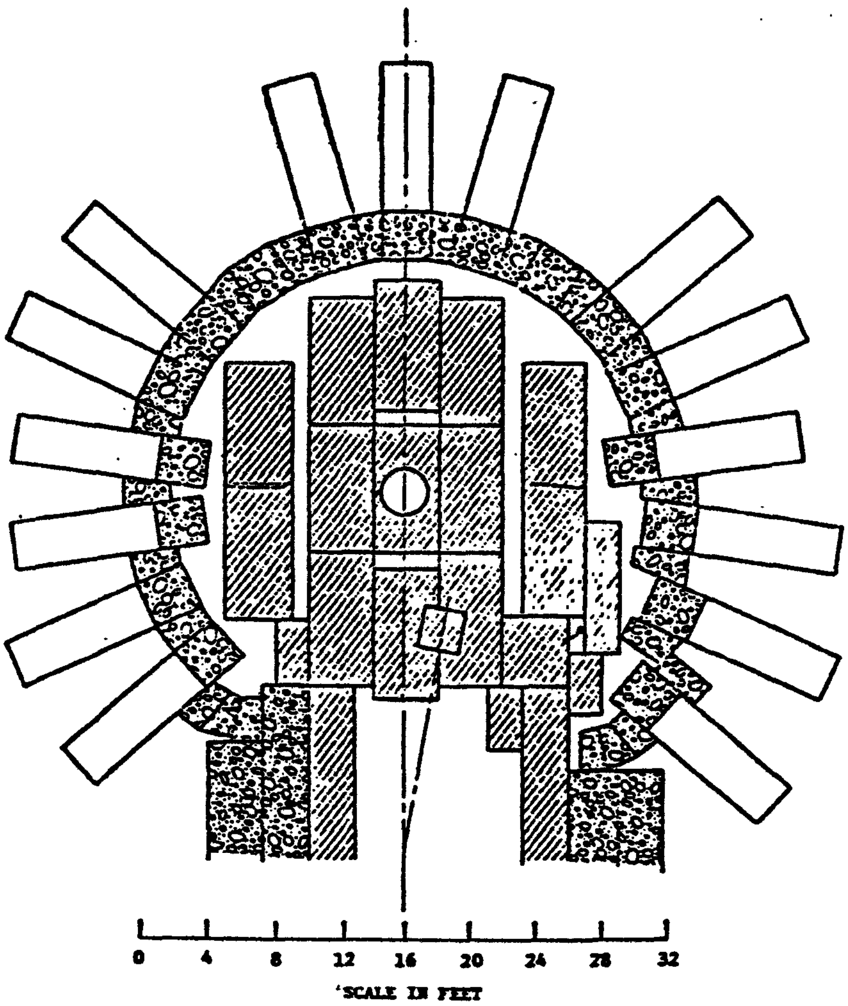


Fig. II-S.1. Alternate shield configuration for IPNS-I.

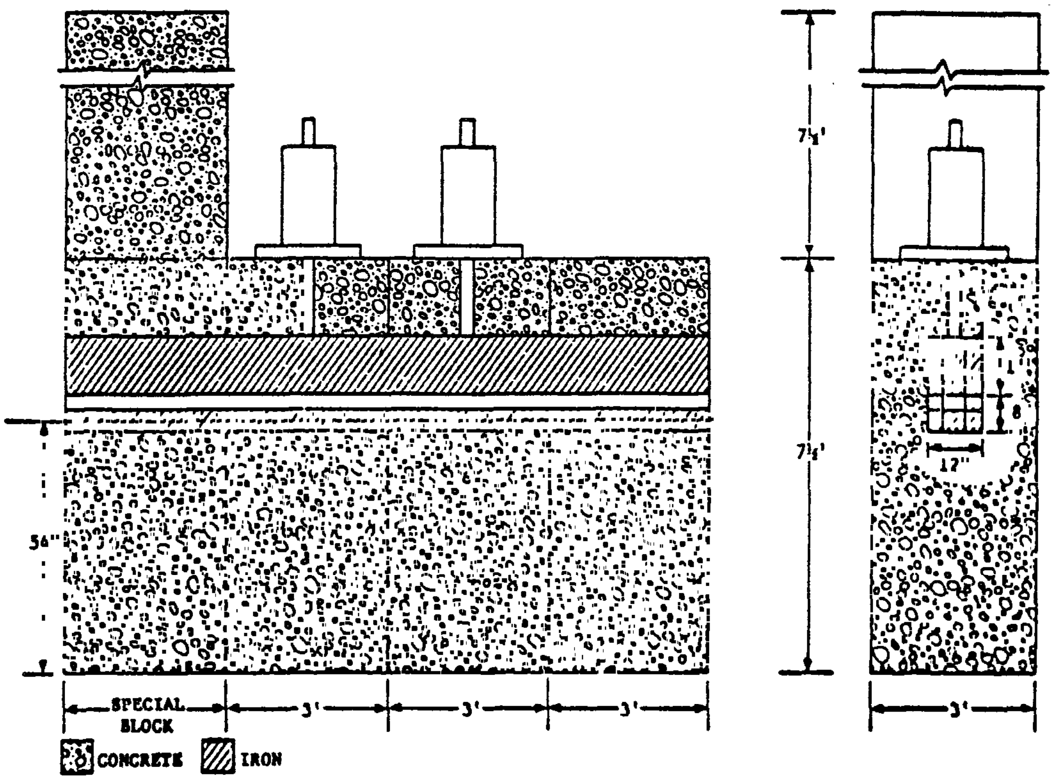


Fig. II-S.2. Penumbra shield and beam gate for the alternate IPNS-I shield configuration.

III. GENERAL SESSIONS - ACCELERATOR TECHNOLOGY

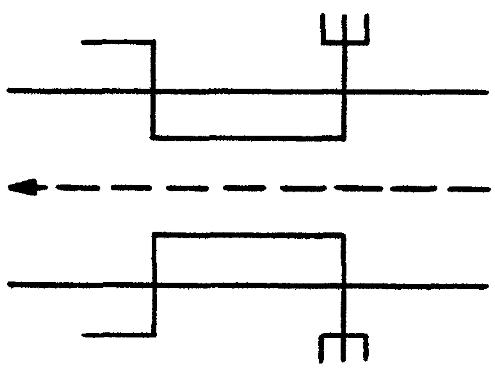
Following the plenary sessions, areas of common interest were determined and a preliminary schedule for the remainder of ICANS-III was adopted for discussions related to accelerator technology.

The basic approach for each topic decided upon was to have a few individuals discuss their advances and/or operating experience, identify the problem areas, and then use that to launch a broader discussion. During the discussion periods specific inquiries were made and plans and ideas for the individual projects were bounced off other experts in the room.

Much of the text for the topics chosen stems from questions and discussion. No attempt has been made to identify the questioners; summaries related to the various discussions follows.

A. Extraction Systems, D. W. Hudgings, LASL

The kicker magnet specifications adopted at this time call for an 80-Gauss, 3-m long, 3-inch aperture magnet to be used for horizontal extraction. One approach considers a parallel plate device operating in the TEM mode (see the sketch below).



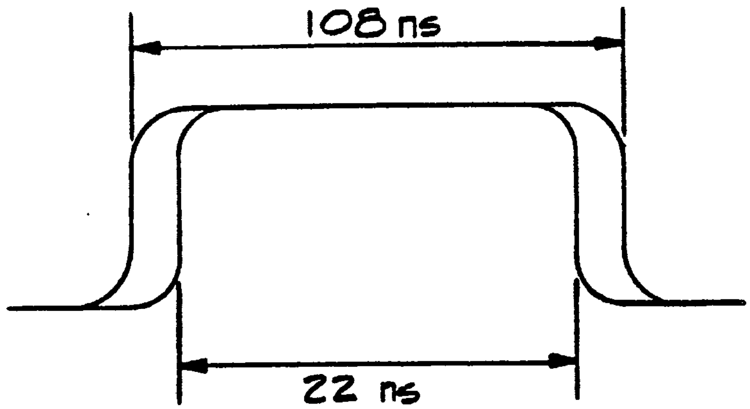
$$F = q(\varepsilon + v \times B);\ E = cB$$

So

$$F = F_m(1 \pm 1/\beta)$$

The sign in the equation depends on the direction which you drive the magnet. For our choice here, we pay the price that the time window is less by the transit time plus the filling time.

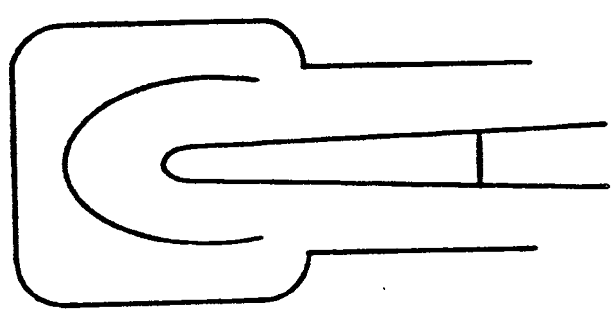
For the pulse requirement we do not separate the jitter and the rise time (as shown in the following sketch).



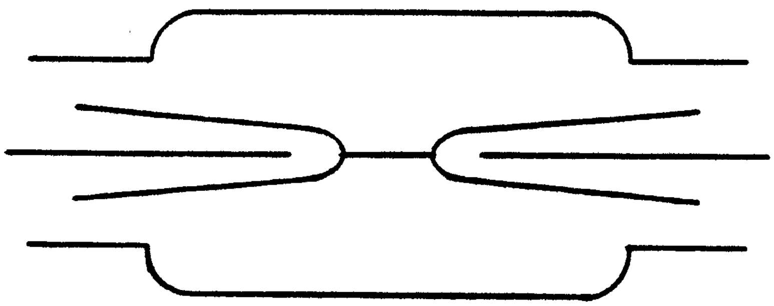
For a 3-m structure the pulse amplitude required in the push-pull mode is ± 50 kV.

For switching at low-repetition rates, spark gaps are all right, but for high rates their lifetimes (~ 10^7 shots) are a serious limitation. For 10^8 shots a day this would be 10 gaps. The lifetime of a thyratron is shortened by high-repetition rates also since it enters a resistive phase when it turns on. This causes a 1-kV arc drop and accelerates energetic ions towards the cathode. Expected lifetimes are 10^7 to 10^8 discharges which requires replacing thyratrons at a rate of once a day and is accompanied by prohibitive cost.

So if one settles for the transmission line approach, this means switch development. We have been looking at thyratrons and another concept called a magnetic modulator. The laser people are trying to develop switches like this. We have one to test. The test fixture will have solid state switching for charging as indicated by:

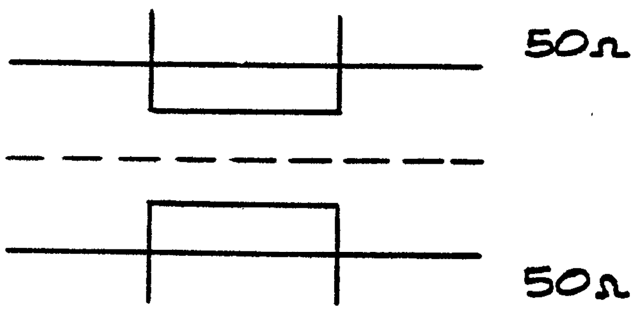


or a push-pull version shown below.



The idea is to use either this or a transformer pulse forming network.

Simultaneity is important because without it you get reflections which bounce around and hurt you later (see sketch below using 50 Ω):



1. Questions

Why not use 10 Ω? Because you have to switch five times the current.

What about deflection quality and will there not be field distortions? The answer to these questions lies in shaping the plates. In this application we are talking about 50-MW peak power so repetition rate is the problem. Our real hope is the magnetic modulator.

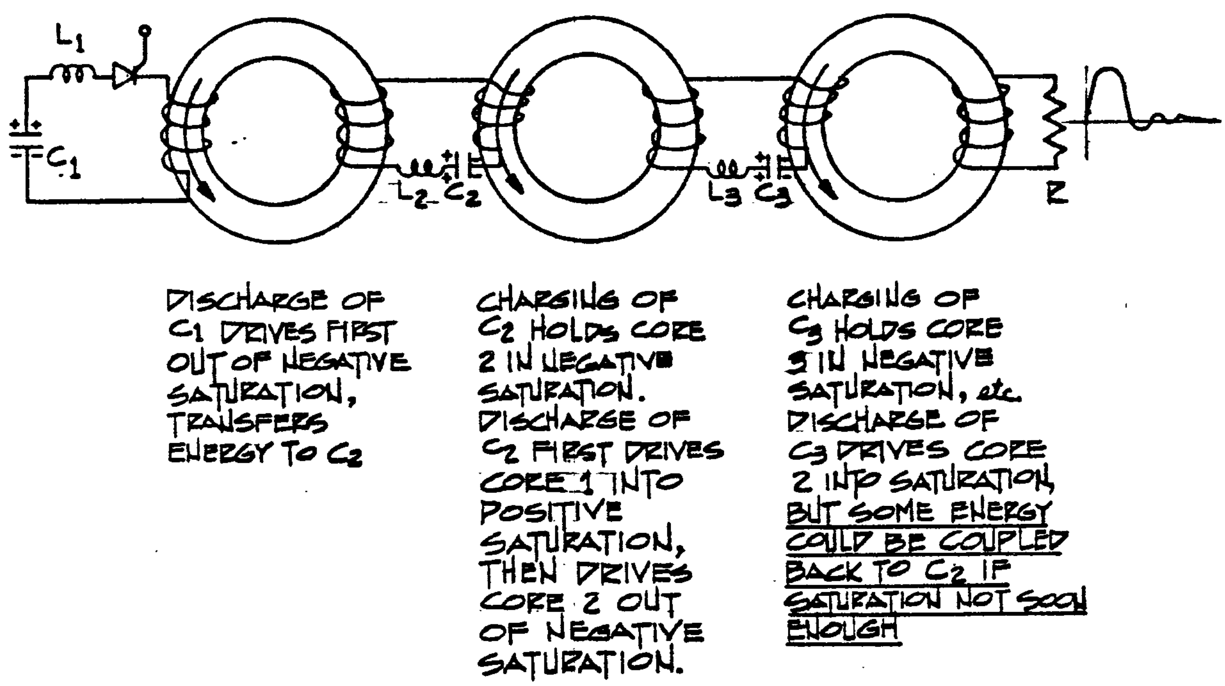
Why not use a system like the CESR kicker? We looked at it but it uses spark gaps. The other problem is that with the ferrite outside the vacuum chamber one would have to metallize the walls and to get field penetration would result in distortion. The high resistance would also exceed that of the entire rest of the ring (200 mΩ).

What is unique about Laser thyratrons? They have larger cathodes, a gradient grid, are compact for low inductance, much beefier, have low jitter but are more difficult to trigger (it takes at least 500 V). The major differences are the large reservoir and cathode.

What is the deflection uniformity across the beam transversely? About 10%, but again the plan is to put tips on the plates or to use curved plates. The ratio of the plate-width to the usable-region-width is ~ 3:1. We can show the computer field calculations if desired.

B. Magnetic Modulator, R. K. Cooper, LASL

The magnetic modulator is a series of saturable transformers with an initial condition in which all cores are saturated in the same direction. When the capacitor discharges, the core looks like a free-space inductor. The transfer of energy from the primary to the secondary depends only on the capacity in the secondary (see the sketch below):



This then becomes the primary and the next one is the secondary. A pulse forming network is used after the second core. We have to time the second core properly as energy is transferred since there is no diode on this stage.

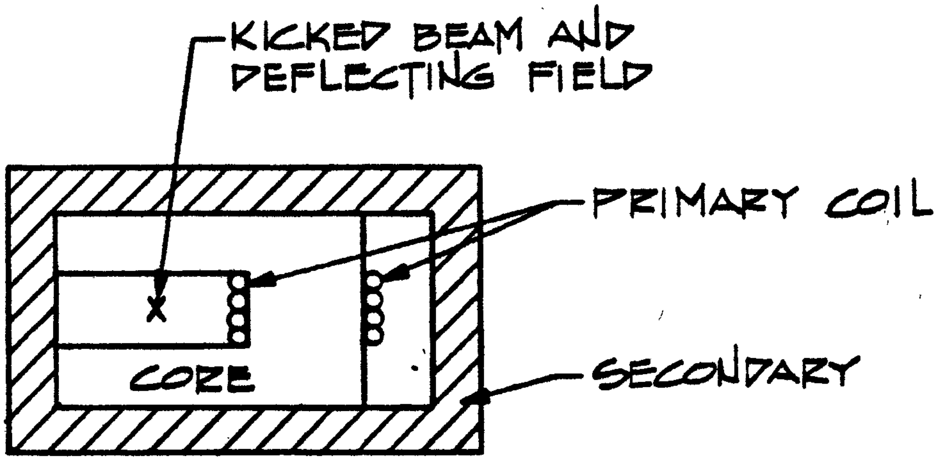
The plan is to use a five stage device and the delivery time is about six to nine months for a system to do what we want.

1. Questions

Isn't it hard to believe you can get ns accuracy? We expect typically 5 ns with overall jitter of 10 ns. The material is called Deltamax and is made by Arnold. They have been used for radar modulators. The cores for this design are about 9-inches diam by 3-inches wide.

C. Pulsed-Septum Magnet, M. H. Foss, ANL

A thin (¼-inch) pulsed (1 Tesla) septum magnet is used at the Argonne Rapid Cycling Synchrotron, but this magnet fails too soon. A good magnet should last 10^9 to 10^{10} pulses. We have tried to develop a better device which consists of a primary coil wound on a "C" core (as shown below).



If this structure were surrounded by a superconducting box then the desired deflecting field would be produced in the gap when the primary is pulsed. This suggests that a grounded conducting box will contain the stray field for a limited time. This box is the secondary. Electrical considerations are minimized in this design so that the mechanical problems can be given full consideration. Details are given in Ref. 1. The pulsed septum magnet is to be followed by a conventional dc magnet.

1. Questions

How do you constrain the primary? Fiberglass and epoxy are used. One could leave the core out of the primary and have zero force on the primary but it would take twice the power.

Do you presently have any beam loss on the system? Yes.

What is the PSR beam size at the septum? About 2-cm half width.

Could you increase the efficiency with a small-back yoke? A small-back yoke will be included in the box.

Reference

1. M. Foss, K. Thompson, and W. Praeg, "A Transformer Septum Magnet," paper J3 of 1979 Particle Accelerator Conference.

D. H^- Injection, Y. Cho, ANL

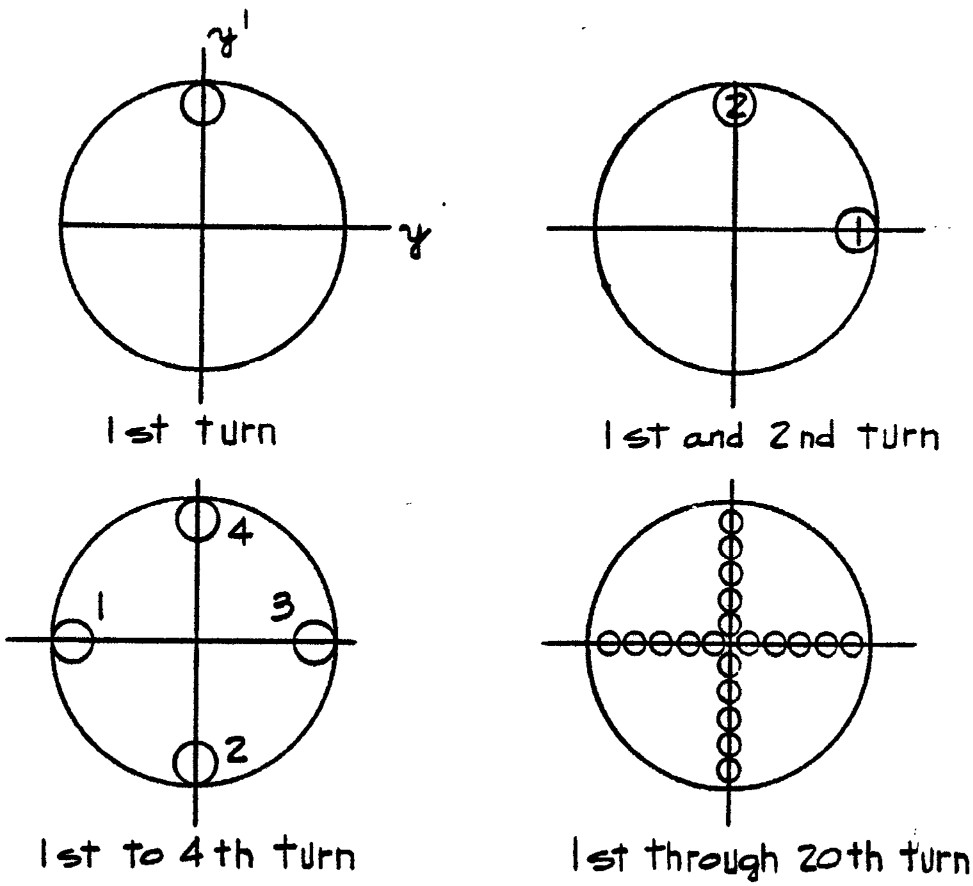
Let us consider the emittance of a linac and the acceptance of circular rings. For example IPNS II and SNS have acceptances of:

$$\left.\begin{array}{l}\varepsilon_H = 60 \text{ cm}\cdot\text{mr} \\ \varepsilon_V = 50 \text{ cm}\cdot\text{mr}\end{array}\right\} \quad \text{SNS}$$

$$\left.\begin{array}{l}\varepsilon_H = 80 \text{ cm}\cdot\text{mr} \\ \varepsilon_V = 40 \text{ cm}\cdot\text{mr}\end{array}\right\} \quad \text{IPNS-II}$$

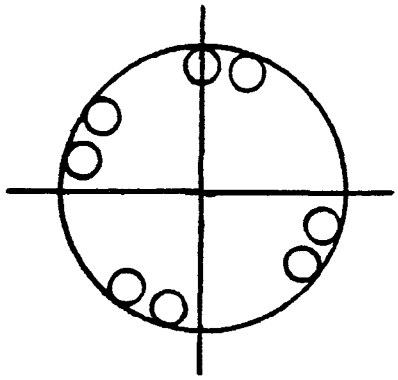
Both machines take linac emittance, $\varepsilon_L \approx 1$ cm•mr. Therefore, in principle for IPNS II one can inject 80 x 40 = 3,200 turns, and for SNS 60 x 50 = 3,000 turns based on the acceptance consideration. However, IPNS II is designed to inject 500 turns. and 300 turns for 8 ns. Thus, there is disparity in the number of turns one can inject into the circular machine and number of turns one intends to inject. Even if one takes into account some factor of two dilution in emittance, there still is a large disparity in the possible number of turns one can inject and the intended number of turns. Thus we have to consider how we are going to inject.

Now we consider the phase space filling of turn by turn at a given point in the ring, and assume the tune of machine is N + ¼, i.e. 2.25, or 4.25. The following sketch shows turn-by-turn filling.

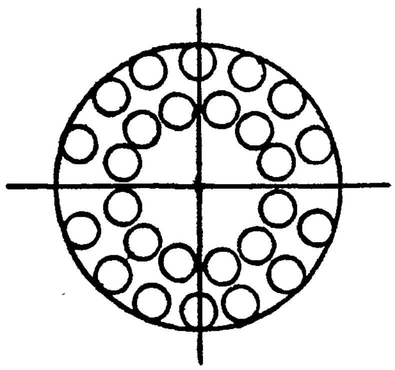


In the above sketch we assumed for simplicity that the space charge effect is turned off, and can conclude that the charge distribution in real space is lumpy.

The question is then what one has to do to fill the beam uniformly in either real space or phase space. Here again we first consider the case with no space charge effect. We make the tune of machine $\nu = N + 1/4 + \delta$, and δ will be controlled by adjusting the lattice elements. Under this condition, filling will be as shown below.

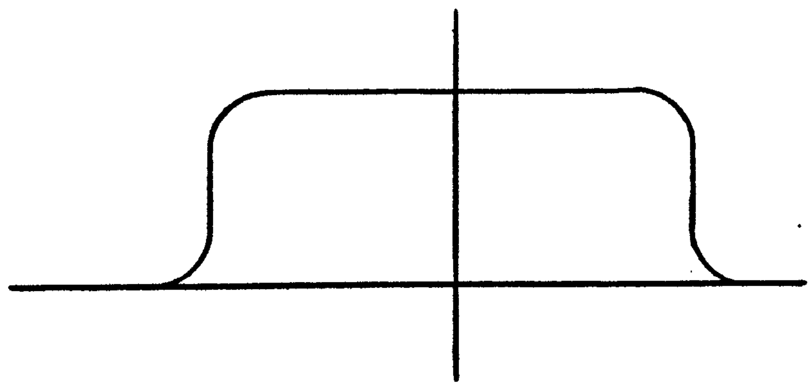


The separation shown in the above sketch is related to δ in the tune, and as the filling of the outer part of the acceptance is done, then the injection angle and the parameter δ are further adjusted to fill the inner part of the phase space as shown below.



Thus by adjusting the injection angle and δ, one can achieve the desired distribution of charges.

We believe that the best distribution for the space change consideration is uniform distribution in the radial space with tails as shown below for Landau damping.



So far our considerations have been without the space-charge effect; now we consider the space-charge detuning which brings in complications. However, the solution is still there as long as we maintain $\nu = N + \frac{1}{4} + \delta$ with taking into account the space charge, then similar argument can be made.

E. Injection for the PSR, D. W. Hudgings, LASL

For H^- injection at 800 MeV, a bumped orbit is hard because there is only about a 4.5-m straight section. It also may not be good to keep the beam on a foil for the full 8 ms. Pulsed bumps would be especially difficult in the short-pulse work.

An alternative is to use neutral-beam injection whereby a magnetic field strips off the first electron. The beam continues to be further stripped by the moving wheel with foils (as ANL does in Booster II). Gas stripping is only ~ 50% efficient and is not practical here.

Using magnetic field dissociation, the stripping length needed is about 1 mm at 1.8 Tesla. This is an extrapolation of other data so measurements are to be made on a ps scale, but using the extrapolations we propose a length of 6 or 7 mm at 1.7 Tesla to get 100% stripping while adding 1 mrad to the beam half angle.

The suggestion is to bias the magnetic field to increase the gradient and cut down on the beam spread. The magnet is planned to have ~ 1 cm aperture and may be incorporated into some other magnet body. There will be some bend involved but less than a degree (probably a few mrad). This magnet may also be used to degrade beam emittance but this has to be studied further.

F. Direct Extraction H^- Sources, P. W. Allison, LASL

These sources were developed in Novosibirsk and currently Fermilab is using one (a magnetron type) operationally with a 0.1% duty factor. A 4-mA average current source with 120-mA peak pulses should exceed the LAMPF requirements. With cooling this type of source should work.

The brightness of the direct extraction source is 1-2 orders of magnitude higher than for proton sources. Also,

$$B_{norm} = \frac{2i}{\pi^2(\varepsilon_{x,norm}\varepsilon_{y,norm})} = \frac{50A}{(cm \cdot mrad)^2}$$

for my source at the 50% contour level.

The advantages of a direct extraction source are:

- only negative ions are extracted
- gas can be pulsed so gas load is moderate
- the magnetron or Penning source is preferred over the duplasmatron because no electrons come out.

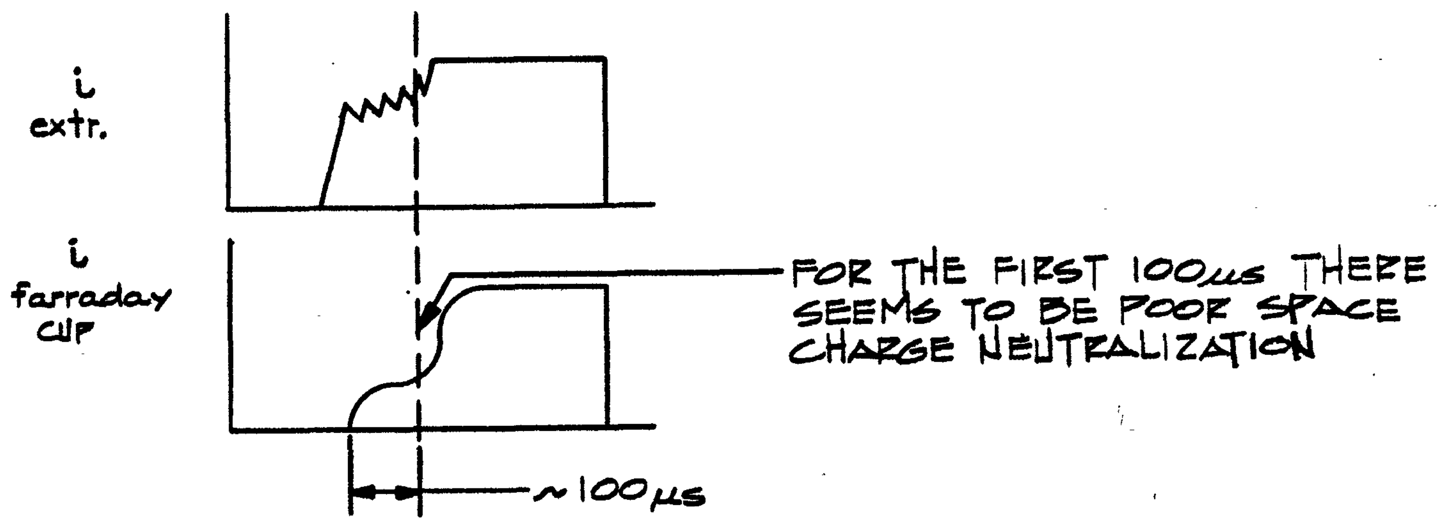
The disadvantages of a direct extraction source are:

- gas economy low, ~ 1%
- uses cesium, but consumption is low
- has never run 120 Hz, 40 mA, 500 μs
- long repair time (~ one day including conditioning)
- LAMPF source has about one month lifetime.

The lifetime is limited by erosion of materials. Insulators have to be good for about 20 kV. We are currently working on a 100-mA CW source with a spinning electrode (for cooling).

We have used both the cesium dichromate mixture and the cesium boiler but the mixture is simpler to handle. The ultimate choice is determined by which puts out a better supply of cesium, and so far the chromatic mixture seems the best. It has run all day here and for many days at Fermilab. There seems to be some conditioning time (~ one day) after being charged.

No attempts have yet been made to see how fast these sources can be pulsed. Nothing less than a few μs has been tried. It often takes about 200 μs for the discharge to become stable. This is possibly due to the time it takes for build up of cesium around the cathode. On turn off there is a burst of cesium out of the source from what has been trapped on the cathode.



Some test results here:

$$\varepsilon_{x,norm} = 0.05\,\pi\cdot\text{cm}\cdot\text{mrad}$$

$$\varepsilon_{y,norm} = 0.008\,\pi\cdot\text{cm}\cdot\text{mrad}$$

Lifetime (est) ~ 28-mA days

120 mA/ms pulse length @ 12.5 Hz
@ 40 mA current @ 30 Hz, 500 μs.

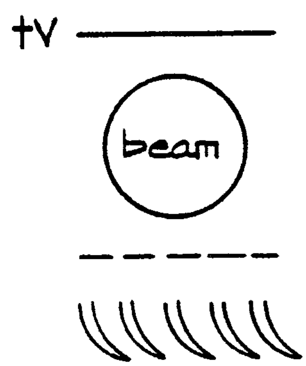
G. The Rutherford Ion Source, R. H. Morgan, RL

This is a simplified version which runs at 50 Hz with 500 μs pulses. The best current so far has been 35 mA but we can only stay in the cesium mode for about 15 min. We have been using cesium dichromate and are about to try the cesium boiler. Once the cesium mode is lost it cannot be regained. We are thinking of cooling the anode and cathode. Two separate power supplies are used. The first is a voltage supply used to start the cesium mode. It then switches to another supply. Possibly we need one supply to do both.

(Allison cpomments) If in switching supplies, the balance of cesium production by evaporation from surfaces is changed, one may need to heat up in a dc mode until the cesium operation is stabilized and then switch over.

H. Position Monitors and Scrapers, I. S. K. Gardner, RL

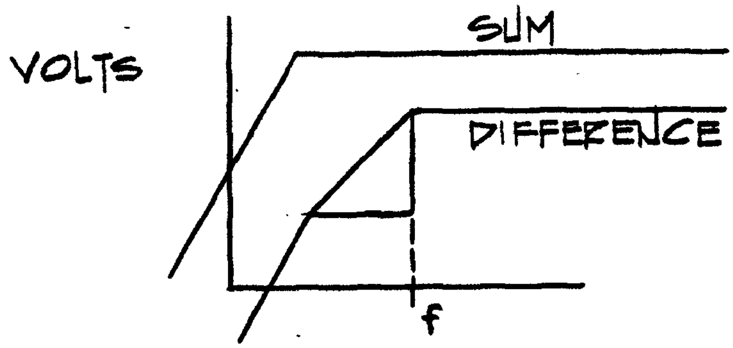
Most of the problems in the beam diagnostics area are with position monitors and phase measurements. It is planned to do profile monitoring with ionization systems possibly with some multiplication devices as illustrated in the following sketch.



To be run in some kind of pulse counting mode

array of multipliers (microchannel tubes)

The position monitors have a ferrite core with copper sheath having a gap. (See Fig. III-H.1). We couldn't get reasonable frequency response values (see sketch below) with one turn. Compared to electrodes, the signals are about 100 times weaker. We want accuracy better than 2 mm and will have 15 vertical and 15 horizontal monitors. We also want to be able to read them all within ~ 30 μs. A faster system is being designed looking at just one turn.



For phase detectors there is a problem since rf voltage varies by 40:1 during acceleration. A ratio of 10:1 is about all the present design can handle and we want a resolution of about 5°. The required rf voltage varies with the beam intensity.

The scrapers consist of 15-cm stainless steel coils (spirals) with cooling. They are arranged both horizontally and vertically to get ~ 99% of the beam which scatters from the foils. The radial positionings are more complicated because of dispersion. We are getting a code to run for these calculations now. Vertical motion has only been studied so far. A satisfactory solution for the high-energy halo is still being sought.

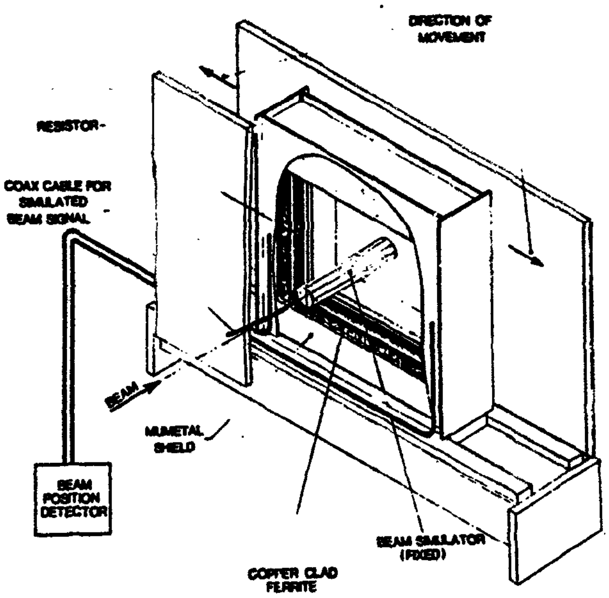


Fig. III-H.1. Prototype beam monitor for SNS.

I. PSR Bending Magnets, R. E. Gillis, LASL

The "H" magnets will be stacked from 1/16-inch thick laminations and will weigh ~ 19 tons. The technique of stacking and supporting the bends is in the formation stage. At this time, it appears that the laminations will not be glued together to give the magnet structural strength because the radiation levels in the ring may be high enough to affect the bonding strength of the glue. The magnet laminations may not be stamped in such a way as to allow the magnet to be split into two halves. By stacking whole laminations instead of half laminations, the stacking process will be faster and alignment of the top half to the bottom half will be eliminated. The installation of pancake coils is not expected to be a serious problem. The coil conductor will be aluminum instead of copper. Studies have shown that aluminum coils will save approximately $100 K in capital cost and save an estimated $1 M in power cost over a 15 year period assuming the cost of power escalates at 15%/yr.

Computer studies, using a finite element stress analysis code, have shown that the magnet can be encased in a metal box where the thickness of the sides and top will be 1/2-inch and the bottom plate will be 2-inches. Such an enclosure should provide sufficient structural support for the laminations and allow the magnet to be supported on three jack stands attached to the tunnel floor.

Several magnet support systems were presented by AT-3 personnel as possible candidates to support the ring-bend magnets in the PSR. All designs shown consisted of a jack screw with some type of self locating device such as a ball and core or a spherical washer thrust bearing. It is hoped such a support screw will allow the bending magnets in the ring to be replaced, in the event of damage, without realignment (see Fig. III-I.1.).

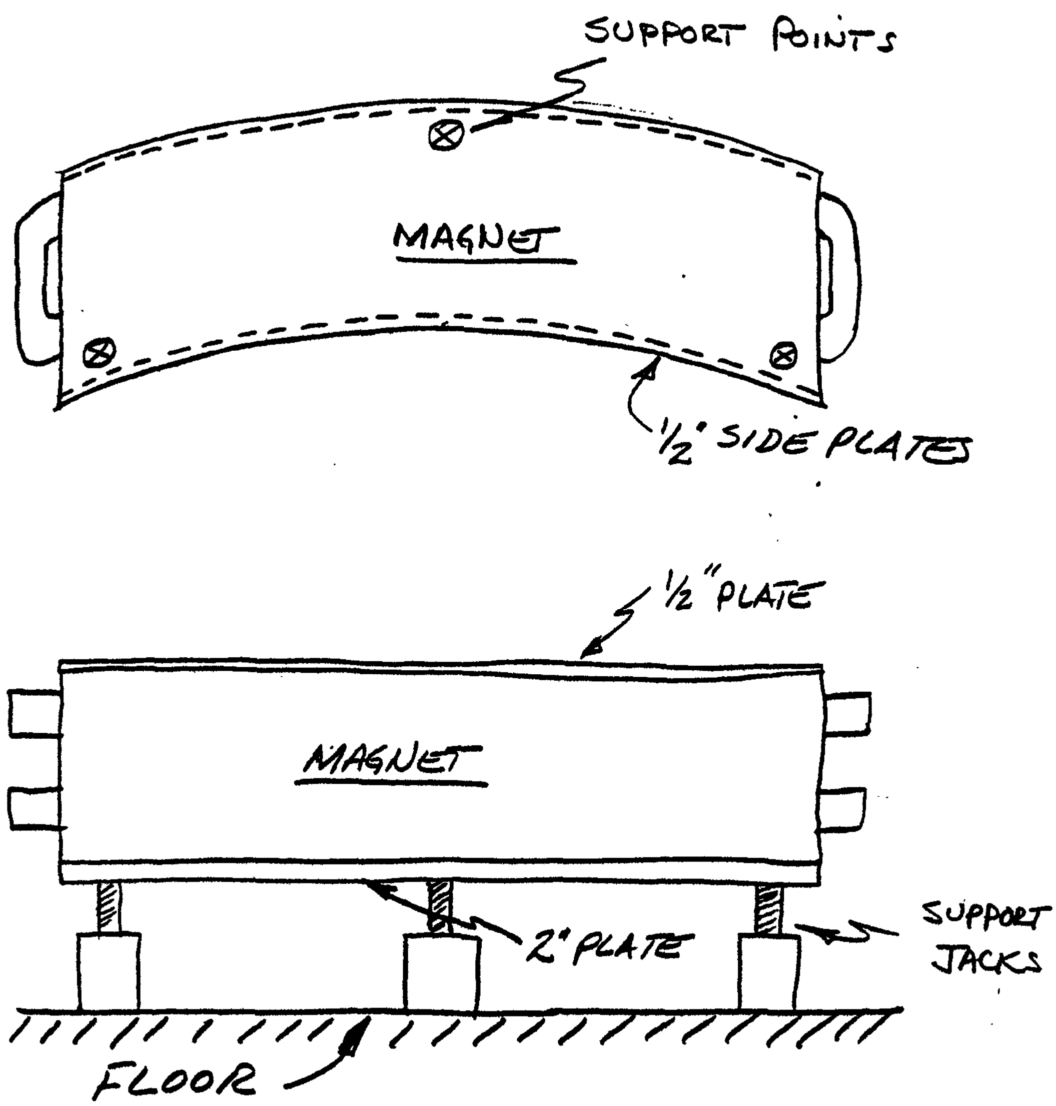


Fig. III-I.1. PSR bending magnet support system.

J. Magnets for the SNS Synchrotron, M. R. Harold, RL

The 50-Hz SNS dipole magnets, which are 4.4-m long and have a 7-m radius of curvature are combined function magnets having a low gradient $\beta'/\beta\rho = -0.68\ m^{-2}$. The magnets are split horizontally in order to allow the flanged ceramic vacuum chamber to be fitted. The H-section laminations will be fanned and resin-impregnated to prevent chatter. Short (~30-cm long) blocks will be formed in this manner and straps welded along the outside to provide flexural strength. The blocks will then be mounted on a massive concrete base, care being taken to ensure that tolerances are maintained, and the blocks tied together with welded straps. The upper blocks will then be mounted and strapped together in a similar manner. Top and bottom halves will be clamped by bolts, and a lifting frame used to remove the top half when necessary.

The coil conductor will be formed from four water-cooled subconductors which are insulated from one another; the conductor will be transposed at intervals to prevent excessive eddy current loss. A glass-mica epoxy insulation will be used.

The programs TRIM, GFUN, and BIM have been used to optimize the shims and ends of the magnet. Field quality must be maintained such that $\Delta\beta/\beta \approx 1$ or 2×10^{-4}. GFUN and BIM agree quite well and for the moment we have more confidence in these two programs. GFUN (3D) has been found to give excellent results at CERN on at least two very short quadruples.

The dipole has just gone out to tender. Two of the three quadrupole types are now on order; design of the third is almost complete and that of the octupoles and beam bump magnets well under way. All the magnets, apart from the dipoles, are short compared with their apertures, so that end effects have to be compensated for by extra shimming. Our dependence on 3D magnet programs is therefore very great but as a backstop we shall be ordering prototypes of all magnets.

Magnet parameters and further details are given in Ref. 1.

Reference

1. R. T. Elliott, J. A. Lidbury, and M. R. Harold, "Synchrotron Magnets for the SNS," paper presented at the 1979 Accelerator Conference.

K. Summary Report on Hardware, Magnets, and Vacuum Systems, R. W. Higgins, LASL

Los Alamos Scientific Laboratory group AT-3 presented R&D activity on vacuum flanging and general vacuum aspects of the Proton Storage Ring (PSR) and entertained discussions on related vacuum technology associated with accelerators and storage rings. The R&D effort described by AT-3 involved flange-seal candidates for the PSR amenable to remote handling techniques. Four flange systems (Figs. III-K.1-4) were shown as possible candidates for simplified connection and disassembly activity on the PSR. The seals noted in Figs. III-K.1 and III-K.2 ("k" and "c" seals) are presently under experimental study for leak tightness, ease of assembly and disassembly, and susceptibility to leakage failure under thermal excursions caused by pipe *in situ* bakeout at 260 °C. These seals have operated satisfactorily for lead and silver coatings.

Other candidates employing deformation sealing methods adaptable to guide connection techniques are shown in Fig. III-K.3 and III-K.4. The Belleville-loaded seal shown in Fig. III-K.3 was discussed as a potential candidate having low-flange axial loads but high-radial sealing loads comparable to knife-edge loads of conventional ultra high vacuum sealing systems.

The modified ConFlat system shown in Fig. III-K.4 was shown as a potential candidate having known and reliable ultra-high vacuum sealing characteristics, but employing a modified marmon block clamp system capable of maintaining the high axial loads necessary for deformation sealing of the ConFlat seal ring, but requiring an auxiliary initial clamping system before the marmon block clamp is emplaced.

Discussions were undertaken on equilibrium and bakeout pumping requirements for small storage rings, with representative pumping profiles given for an elemental section of the PSR, shown in Fig. III-K.5. High throughput pumping with turbomolecular pumps was discussed with particular experience given by Argonne National Laboratory personnel on backstreaming studies they have done with vertical axis turbomolecular pumps. Residual gas analysis of the molecular species in beam pipes in the immediate region of turbomolecular pump inlets detected no oil vapor species even with heavy contamination of the pumps at their discharge ports. These results appear to be considerably sound with the high rotor speed turbomolecular pumps.

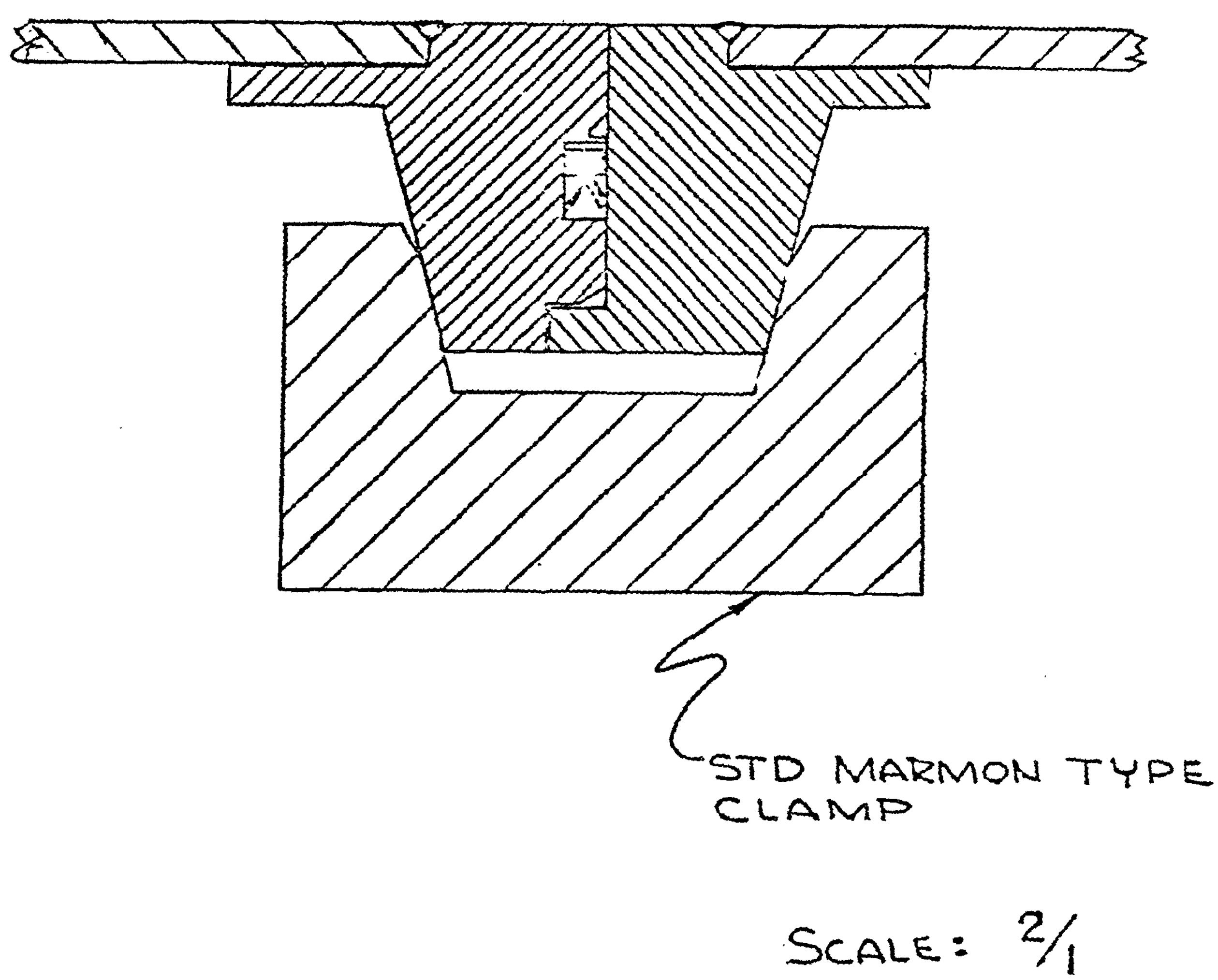


Fig. III-K.1. "k"-seal marmon clamp.

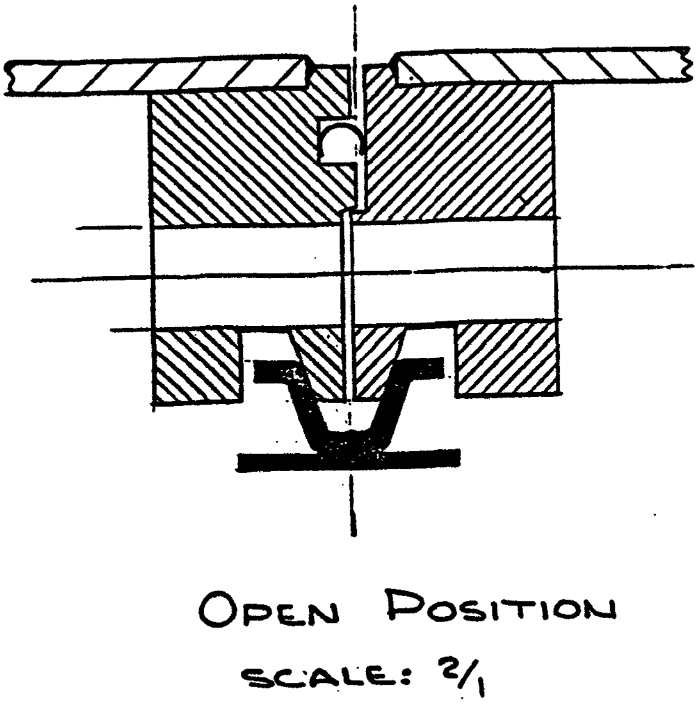


Fig. III-K.2. "C"-ring yoss clamp.

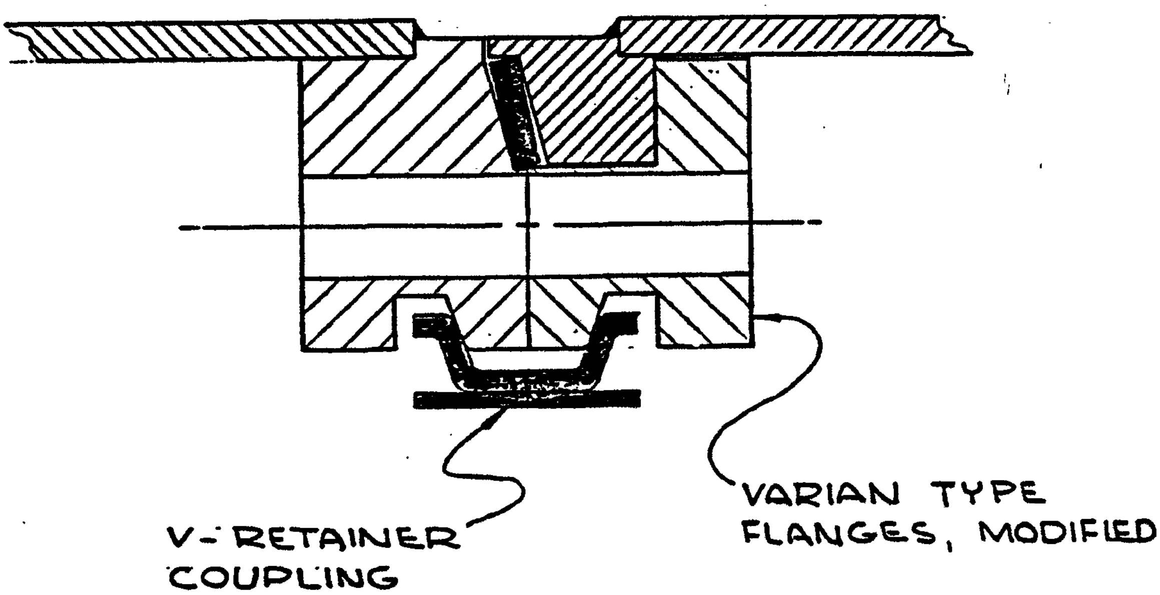


Fig. III-K.3. Belleville-ring-seal voss clamp.

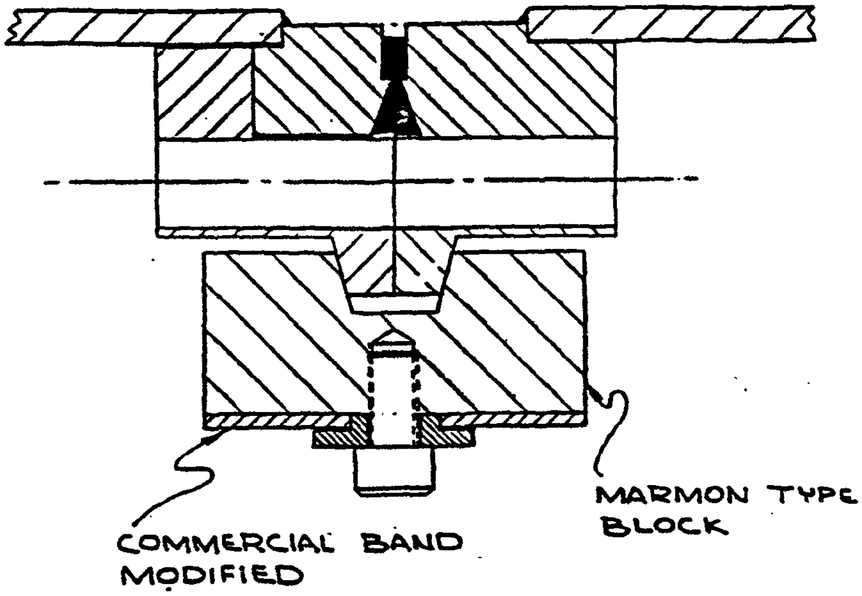


Fig. III-K.4. Conflat-seal marmon block clamp.

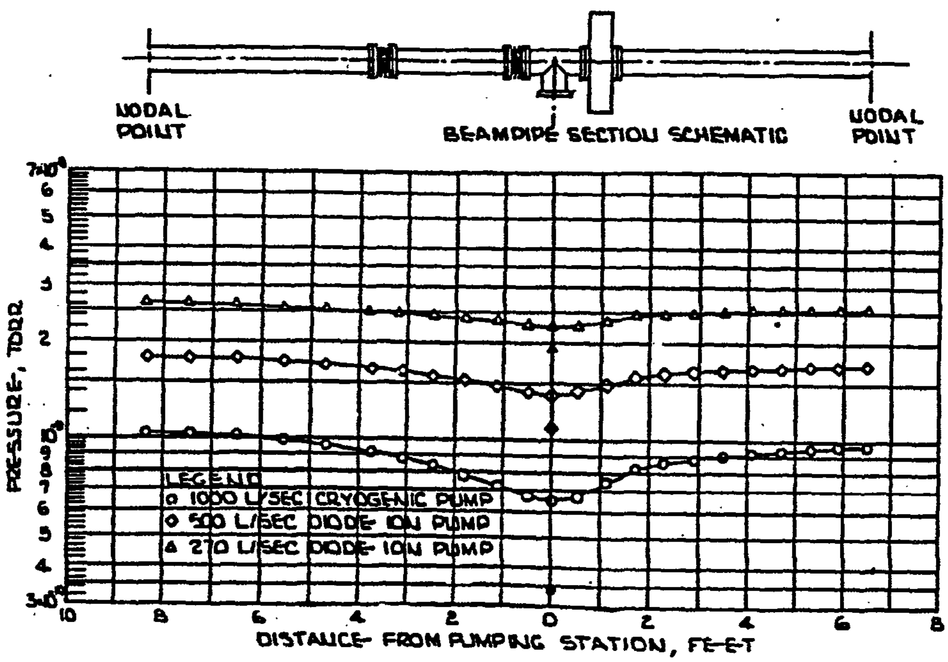


Fig. III-K.5. Pressure profiles for a typical 6-inch O. D. beampipe segment.

L. Summary Report on H^- Ion Sources, D. R. Moffett (ANL), P. W. Allison (LASL), and R. H. Morgan (RL)

Los Alamos Scientific Laboratory (LASL) reported on their experience with the surface-plasma Penning type source (see Sec. III.F). They have run with a cesium dichromate fill and also an external cesium boiler, and feel that while both lead to much the same results the cesium dichromate fill is somewhat simpler to operate despite the interdependence of temperature and cesium release. They estimate a one-month life for a LAMPF-source candidate of 120 Hz and 40 mA but have not tested a source under these conditions. They have run at various frequencies up to 100 Hz and typically 120 mA, 1 ms, and 7.5 Hz. The extraction electrode is then at about 18 kV dc. They have no difficulty retaining a quiet cesium-mode arc for hours if required, and report no particular difficulty restarting a "run" source which has cooled down. The amount of cesium present, and the applied magnetic field, appear to have a bearing on the degree of noise in the air. Instabilities can be noticed at the start of the pulse which settle down in about 200 μs. The analyser magnet has now been field-shaped to minimize observations in the extracted beam. Typical emittances quoted are 0.05 π·cm·mrad horizontally, and 0.008 π·cm·mrad vertically. No experiments on cooling the source have been done at Los Alamos.

The rotary-cathode 100 mA continuous source for the Fusion Materials Iradiation Test Facility was briefly mentioned. Tests are in an early stage as yet on this source.

ANL was almost ready to start tests on a Penning source with a cesium boiler and an arc powered from a 90 μs delay line with Z = 1Ω. The extraction electrode will be pulsed with 20 kV. No provision is made for cooling the source, but a heater is provided to assist in starting the source. They hope to have 30 Hz operation at 40 mA and 75 μs by summer 1979.

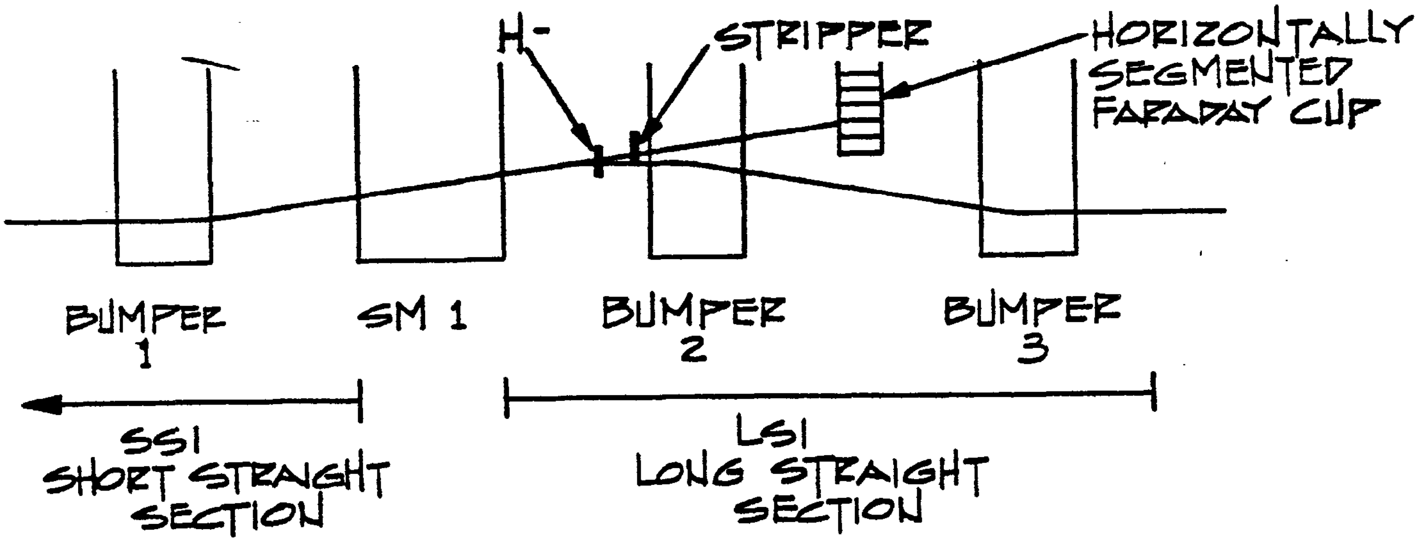
Rutherford Laboratory has run a simplified version of the Penning source with cesium-dichromate fill, and have obtained 35 mA of extracted unanalyzed beam. However, they report difficulties in maintaining a quiet cesium arc for longer than ~ 15 min, and it was suggested that either some contamination was occurring or that the arc supply voltage should be more than the 200 V quoted. They are about to test an external cesium boiler, and a rig containing an analyzer magnet is being built.

M. Injection Diagnostics and Booster II Operating Experience, Y. Cho, ANL

There are 12 sets of wire scanners distributed between the linac and the RCS injection point. These provide vertical and horizontal positions and profiles. Also, there are two toroids; one at the linac and one just before injection into the RCS for measurement of transmission of 50 MeV H^- beam. We typically inject ~ 5 mA for 40 to 50 μs.

The ring is divided into six equally-spaced long and short straight sections. A Faraday cup is located in L6 which is almost one full revolution around the ring. The two toroids in the 50-MeV line and the L6 Faraday cup are used to measure first-turn coasting efficiency.

A sketch of the injection orbit with the bumpers and strippers are shown below with the curvature of the central orbit removed. By turning off all the bumper magnets and removing the stripper, the injected H^- beam profile can be seen on the segmented Faraday cup. By inserting the stripper, you can strip and unstrip the beam and you can set the position of the stripper. Then, the bumpers are turned on and you can see whatever H- beam that occurs on the original H^0 position but with opposite polarity.



There are two 50% transparent Faraday cups situated in the L3 and L4 straight sections. The injection angle is adjusted by looking at first, second, and third turns.

When the injection angle is properly adjusted and the Faraday cups removed and the ac field off on the main ring magnets, the coasting beam will last for 2 ms with 2 x 10^{12} protons circulating in the ring. Under coasting beam conditions, rf capture is 100%.

Since we have no pulsed vertical steering magnets, similar studies have been undertaken for the vertical injection as was done for the horizontal injection.

There are six position monitors in the six short straight sections. The design of the original position monitor was 2-inches by 2-inches high by 4-inches wide. They were cut into four pieces on the diagonals so that simultaneous horizontal and vertical measurements could be made. The drawback with this configuration is the cross-coupling created by midplane tilts. Consequently, we have designed two new electrodes which are x-sensitive and y-sensitive only. They are installed and will be tested shortly.

The signals from the four segments of one of the position electrodes are added together and used as a fast Q-signal electrode. This signal is fairly clear from its noise and is used for beam phase feedback. The cable picks up RMPS noise which does not effect beam phase feedback, but we would still like to eliminate it. A slow position signal from the electrodes is used as position feedback in the rf amplifier.

We have one horizontal and one vertical residual gas ionization type beam profile monitor. The horizontal device gives a good measure of beam width. For circulating beam emittance measurement, we should have more than one at different points of the β-function.

For extraction, we have an extractable segmented wire ionization chamber (SWIC) in front of the extraction septum magnet. We have occasionally hung a glass plate outside of the ring. With 10^{13} bombarding protons, a beam profile measurement has been made which provides some information which is not obtained electronically. A long tail on the extracted beam is one example.

There are three more SWICS and two toroids further along the 500-MeV transport line. All the SWICS can be used for centering the beam. The last SWIC is just before the ZING-P' target and is always in the beamline for monitoring position and size on the ZING-P' target. The other two SWICS are normally removed from the beamline after tuning.

The two toroids in the 500-MeV line tend to pick up kicker noise because of the time coincidence. This problem is still being worked on and hopefully will be resolved.

We use the kicker magnets at low field level to produce a fast coherent oscillation and analyze the fast position signal with a spectrum analyzer.

1. Question:

Do you really need profile monitors in L3 and L4 for injection profiles? You want to match the α and β emittance to avoid unnecessary beam losses and to optimally fill the acceptance of the ring.

N. Radio Frequency Shielding, C. W. Planner, RL

The SNS will use a ceramic vacuum chamber in the regions with magnetic fields, since the fields oscillate at 50 Hz. Our calculations show that the rf wall impedance will be too high for stable beam motion unless something is done to modify the selectromagnetic environment of the beam.

In the SNS, the longitudinal coupling impedance is dominated by the capacitive term, which contains the factor $(1 + 2 \ell n\ b/a)$. We propose to minimize this term by making the chamber radius b equal to the beam radius a. We will follow the beam profile around the machine with a boundary which terminates the beam electric field.

For the transverse coupling impedance the space change term again dominates and contains a factor $(1 - a^2/b^2)$. This term can again be minimized by making a and b close to one another.

The boundary which terminates the space charge field will consist of an array of 2-mm stainless steel wires top and bottom running longitudinally, with plates at the sides in the bending magnets. These conductors permit the synchrotron magnetic fields to penetrate, but electric fields will terminate on the wires and plates. The quadrupole magnets will have no plates, just wires over the pole tip areas.

O. Theory on Beam Induced Electron Multipactoring, L. Z. Kennedy, LASL

Beam induced electron multipactoring is the production and multiplication of secondary electrons as a result of the transverse accelerating fields of many proton bunches acting on a few initial thermal electrons. A simple calculation indictes the possible severity of the problem.

Let N_o = number of initial electrons

N_n = number of electrons after passage of n proton bunches

Y = average secondary electron yield

$N_n = Y^n N_o$.

We have calculated Y for both the short and long bunch cases for PSR, and for aluminum and stainless steel vacuum chamber walls:

	Short	Long
Aluminum	1.41	1.50
Stainless Steel	1.14	1.30

The figures for Al assume relatively clean surface. A possible result of electron multipactoring is desorption of gas from the walls. The above figures, if anywhere near the truth, indicate strong electron buildup and possibly a severe problem. SPEAR has not reported any such prolem, but there are worries about this at Isabelle. There is some fear that electrostatic position monitors may not work. We are investigating this problem with a hardware simulation.

Suggestion from audience is to flash titanium on the surface and forget it.

P. Apparatus for Measuring Beam Induced Electron Multipactoring, G. Spalek, LASL

The surface of the wire becomes part of the experiment. Does not simulate actuality. These are very small wires, but fields are high (completely different). We could read current on the central wire to see if we have a two-surface effect. Flashing Ti is expensive for the whole ring. Titanium pumps and holds gas, worry about pressure bumps. Titanium chambers are better for pressure bumps. Investigate CERN and PEP experience.

Q. Disk and Washer Structure, S. O. Schriber, CRNL

Efficiency of converting rf power to useful beam power was improved by the shaping of cavities as in the high-energy portion of LAMPF and other operating accelerators in the standing wave mode. Additional advantages were realized by selecting the $\pi/2$ mode as the operating mode. Introduction of the disk-and-washer structure interested many laboratories because of a factor of ten increase in coupling constant. Although rf conversion efficiency was slightly less than the LAMPF shaped cavities, the increase in coupling constant suggested that longer structures could be built and that tolerances would be improved.

A comparison of the LAMPF structure and the disk-and-washer structure shows that the disk-and-washer has an extra degree of freedom. Frequency characteristics are fixed by adjusting radii of the washer and the disk, while the outer cylinder radius can be selected to obtain better rf characteristics. As with the LAMPF structure the gap was optimized to give highest efficiency. Optimum disk width was also determined. Present calculations have shown that the choice of a large outer radius leads to improved rf conversion efficiency (up to 70% higher than an equivalent LAMPF structure), improved vacuum conductance, and more varied assembly methods.

The outer radius selected for most applications should not exceed 17 cm at 1.35 GHz to ensure that mode interference is not a problem and to maintain a high group velocity. With this restriction rf conversion efficiencies are 30% higher than an equivalent LAMPF cavity for $\beta = 1.0$ (ZT^2 at 1.35 GHz is 91 MΩ/m compared to 69 MΩ/m).

Radial supports are the preferred washer support because they represent a symmetrical support method. Experimental bead pulls with L supports (the original support) and T supports showed that on-axis fields from cavity to cavity change by $\sim$ 19% because of changes in coupling constants. These changes can be compensated by displacing disks; however, mechanical difficulties are added and the system becomes quasiperiodic.

The disk-and-washer geometry can be used for many different applications, such as, storage ring cavities, proton linacs, electron linacs, etc. The geometry can be chosen to produce a "harmonic accelerator" which will have a time varying rf wave which is almost linear during passage of a beam bunch because the structure can be operated at two frequencies simultaneously - one twice the other. A geometry can be chosen which has high accelerating gradients (40 MeV/m at 3GHz) with a ZT^2 which is larger than an equivalent LAMPF cavity. Beam excited transverse modes can be Q spoiled or loaded by different techniques - outer wall of glassy material such as 304 SS, rotating stems, rotating dimpled washers and adding loading probes.

R. Nonintercepting Beam Position Monitor, J. S. Fraser, CRNL

The following is a summary of a paper by J. McKeown, CRNL, to appear in Proc. 1979 Particle Acceleration Conference.

Beam tests have been carried out with a cylindrical cavity tuned to 2.415 GHz which is the third harmonic of the accelerator frequency. The beam excites a TM_{110}-like mode when the beam centroid is displaced horizontally and an orthogonal mode when the beam is displaced vertically. The phase reversal detected when the beam crosses the plane of symmetry identifies the quadrant occupied by the beam. The signal voltages are proportional to beam current and displacement with an average slope of $0.35\ mW^{1/2}.mm^{-1}.mA^{-1}$.

The beam couples to the longitudinal electric fields of two TM_{110} modes of a cylindrical cavity. A bimodal cavity was constructed in which quadrupolar symmetry is created by introducing tuning plungers at radial positions near the electric field maxima and four magnetic coupling loops on the circumference.

The bunched beam passes through a 3.8-cm-diameter hole in a cavity which internally is 14.75-cm diam and 6-cm long. Bench tests, in which a common oscillator was used to excite both modes simultaneously through two probes, showed that the relative phase and amplitude of the modes could be varied independently and that the isolation was greater than 40 dB.

In the beam tests the bimodal cavity was traversed horizontally and vertically across the beam. A change of phase of π radians was observed as the signal dropped to zero when the beam was on axis. The signal power was shown to be proportional to the square of the beam current. Mode isolation consistent with the theory was also demonstrated.

S. Beam Light Profile Monitor, J. S. Fraser, CRNL

Studies will shortly be under way at Chalk River National Laboratory on the light emitted by the residual gas in a beam pipe carrying a high-current proton beam. The object of the study is to search for emission bands in the molecular spectra (H_2 or N_2) that are independent of the free-electron density in the vicinity of the beam. If there is sufficient intensity in the visible range (say 400 nm to 800 nm) a beam profile monitor based on light may then be feasible. Various optical devices, for example, linear photo-diode arrays, vidicons, fiber optics, microchannel plate image intensifiers, might be used for recording the profiles.

Using multiple profiles (three or more), the beam current density distribution can be reconstructed using tomographic techniques. If the transfer matrix for high current beams in a drift space is known theoretically, an estimate of the transverse emittance may be made by reconstruction techniques with a nonintercepting beam profile monitor.

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